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Computer-Aided Design AND APPLICATIONS

Digital Film and Television Special Effects Production Based on Virtual Reality Technology

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Abstract. In the past, virtual digital film and television special effects production often failed to meet the audience's immersion and interactivity, which weakened the overall experience of the audience. In order to enhance the immediacy and experiential nature of film and television special effects, the production of virtual reality technology film and television special effects requires the analysis of stereoscopic visual effects. This article simulates real 3D scenes and virtual reality environments in the production of digital film and television special effects based on virtual reality technology, which brings more possibilities and creative space for film and television production. A special effects 3D spatial model was created using SLAM and Kinect technology. Through 3D registration, the authenticity analysis of the overall 3D special effects of the student source was achieved. The research results indicate that the three-dimensional spatial model constructed in this paper has a very accurate and stable attitude estimation effect. This reduces the camera pose estimation error in three-dimensional space. And it has improved the overall stereoscopic effect level of the audience's vision.

Keywords: Virtual Reality Technology; Digital Film and Television; Film and Television Special Effects; Special Effects Production
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1 INTRODUCTION

As people's demand for cultural content increases, film and television content topics are constantly innovated and have broken the boundaries of the real world. Many film and television content and scenes will involve ancient history, natural disasters, cosmic space, war, etc. Some of these content and scenes are difficult to achieve by conventional means. Bacharidis et al. [1] performed precise 3D realistic facade reconstruction with computer assistance. Constructed a neural network for monitoring the facade structure. Further improved the graphics rendering and reconstruction of computer vision. With the continuous development of 3D film and television, audiences have a great dependence on utilizing computer technology and digital technology for the development of film and television special effects. The technical means of processing, processing, and modifying the filmed film and television materials to create a more visually impactful and infectious visual effect. Digital film and television special effects are widely used in fields such as movies, TV dramas, and games, which can improve the quality and expressiveness of film and television works, bringing viewers a more shocking visual experience and a richer sensory experience. It can improve the quality and realism of film and television special effects, enhance the viewer's sense of presence and interaction, and even let the viewer become the creator of film and television content, and complete the ideas in his or her mind independently in the virtual film and television world built. Online video conferencing tools and virtual reality (VR) platforms can connect art audiences with each other. The metaverse is a virtual world where live dramas and performances can be presented in digital form, and interaction and communication can take place in the virtual space. Baía et al. [2] brought a new viewing experience to the audience through digital live theater and performance, while also bringing new development opportunities for theater and performing arts. Carpio and Birt [3] provide a VR immersive movie experience for a virtual reality team. By monitoring the entire software and hardware operation process of the VR movie environment experience, it analyzes the precise synchronization between physical and virtual counterparts. The study integrated tactile and stimulus technologies and implemented them in a virtual environment.

This article conducts research on film and television production by combining virtual technology and special effects technology, and summarize the existing literature and research results. Secondly, this paper constructs a 3D spatial reconstruction model for special effects based on virtual reality technology, combines the SLAM of RGB-D camera and Kinect technology to estimate the camera pose, and effectively implements the description of motion trajectory to lay the foundation for 3D reconstruction of special effects environment. After completing 3D modeling, error accumulation is avoided through loopback detection and optimization. The 3D virtual sound technology is combined with AR system and 3D registration of virtual sound sources to enhance the real immersion and perception of special effects in film and television. Finally, this paper designs and compares simulation experiments to verify the applicability and feasibility of the constructed 3D spatial reconstruction model and 3D virtual sound model for special effects based on virtual reality technology, and realizes the verification of the accuracy and effectiveness of special effects production based on virtual reality technology in film and television by analyzing the absolute errors of different camera pose estimation results and different optimization algorithms in loopback experiments in different data sets. The research results indicate that the accuracy of the results of digital virtual film and television special effects production has a good advantage.

The innovation of this paper is the combination of virtual reality technology in digital special effects, which enhances the tracking of special effects motion estimation and the realism of 3D virtual sound through Kinect technology and AR system, improves the accuracy of 3D scene modeling, can adapt to the presentation of film and TV special effects in non-scene, and enhances the immersion and realism of the experiencer. In addition, loopback detection effectively avoids the accumulation of errors in 3D scene reconstruction, improves the accuracy of virtual scene effects reconstruction, and the final presentation of film and television special effects is more in line with the real situation.

2 RELATED WORK

Cui and Sharma [4] have brought many new opportunities and challenges to animation design with the rapid development of digital media art. In digital media art, designers can use various digital media technologies to create more rich, vivid and efficient animation works, including computer graphics, image processing, audio and video editing, etc. For example, computer graphics technology can be used to create more realistic characters and scenes. The use of 3D modeling technology can create more refined models and special effects, and the use of virtual reality technology can provide users with a more immersive experience. In the past, digital technology has become a platform for developing interdisciplinary virtual technology experiences.

Fischer [5] analyzed the realistic alternative forms of immersive environmental physics in movies. It is based on multi-sensory CAD virtual reality technology and examines some movies from multiple perspectives of film aesthetics and technology. Due to the limited attention paid by film and media theorists to innovative and innovative immersive storytelling forms, it is necessary to thoroughly contextualize the storytelling aspect after the movie. It is worth noting that this study adds to the mixed and interdisciplinary nature of aesthetics and technology that supports and reuses these fields. Kerr and Gillian [6] conducted a situational experience digital analysis to examine the level of CAD online education in a virtual environment. Its focus is on analyzing the design principles of key numbers around situational experiences in the discipline. Liu [7] elaborated and analyzed the relevant development of digital media technology. Liu et al. [8] proposed an efficient computer-aided cascaded 3D network architecture. This architecture has been constructed in terms of visual quality and accuracy using 3D neural networks. Achieved unprecedented 3D texture output resolution and fidelity. Online product images have now played an important role in the simulation of CAD virtual environments. Due to the continuous upgrading of products, consumers need to observe and touch the actual products in these digital environments. Therefore, Luangrath et al. [9] discussed the meaning of digital product display management and the analysis of consumer online product images.

Pepe et al. [10] constructed an effective digital 3D model. In order to provide more complete geographic inference for building information modeling, an accurate 3D model is established, It is suitable for both structural analysis and parameterization of rheological and geometric information for each unit of the structure. At present, there are certain limitations in the construction of building information models. Song and Wook [11] have constructed a virtual character interaction system based on IoT sensor technology. Real time capture and imitation of character actions have been achieved through the recognition of virtual character interactions in the Internet of Things using artificial intelligence algorithms. In summary, it has made significant progress in the cross-border film and television fields of AI and VR, and these achievements will be conducive to promoting the application of virtual character interaction systems and improving the effectiveness of VR or AI film and television production. Xu [12] analyzed the interactive conceptual design in immersive animation scenes. By analyzing the basic characteristics of virtual reality animation scenes, it analyzes the immersive scene application of light and shadow digital information technology. Through this study, it has improved the mobility efficiency in the design of rotating animation scenes. Creators of digital media art should consider integrating virtual reality into their works to improve the quality of their creations, especially considering the continuous progress of science and technology. Wilmsherst and Mackay [13] explored the artistic development process of digital media based on virtual reality and explained the uniqueness of its aesthetic design. He also proposed a technology based on virtual reality to create visual space for digital media art. A study was conducted on the spatial visual form in digital media art design from the perspective of visual perception. Yang et al. [14] developed a building informatization method based on three-dimensional digital technology, which can integrate and simulate data and information from various stages of building design, construction, and operation. Generate semantic rich structural BIM models in 2D computer-aided design (CAD) drawings. Yu et al. [15] conducted artistic oriented creation in the teaching mode. The blended teaching mode of "Film and Television Production Technology and Art" based on the OBE concept has been studied and practiced. Through the construction of teaching models, the plan for building students' autonomous learning ability was elaborated. Zeng [16] used 3D modeling software such as AutoCAD, SolidWorks, etc. to establish a 3D model of a building, including various parts of the building, such as walls, columns, floors, roofs, etc. Add necessary information to the 3D model of the building, such as axes, doors and windows, components, etc., and annotate and annotate as needed. Zhao and Zhao [17] relied on CAD digital sculpture technology to produce material types. And the basic characteristics of material animation synthesis were analyzed. The similarity scene simulation of 3D tasks provides convenience for the automatic animation generation system.

3 METHODOLOGY

3.1 Optimized Model for 3D Spatial Reconstruction of Special Effects Based on Virtual Reality Technology

Stereo visual effects in film and television special effects are based on the principle of human eye imaging and can usually be achieved based on perceived lens changes, monocular motion parallax, binocular perception of convergence angle and binocular perception of parallax. The current main display methods are the simultaneous display method with the help of 3D stereoscopic eyes and the naked eye stereoscopic effect display based on alternate display of images at specific frequencies. However, no matter which way the stereo visual display of film and television images is realized, enhancing the anti-interference, matching accuracy and improving the efficiency of special effects production of stereo visual effects has been an important direction of the corresponding algorithm research. In this paper, we choose to carry out 3D reconstruction in film and TV special effects based on RGB-D camera and introduce the measurement of Kinect depth information data to improve the accuracy of dense 3D reconstruction, as shown in Figure 1, the schematic diagram of Kinect depth information measurement principle.

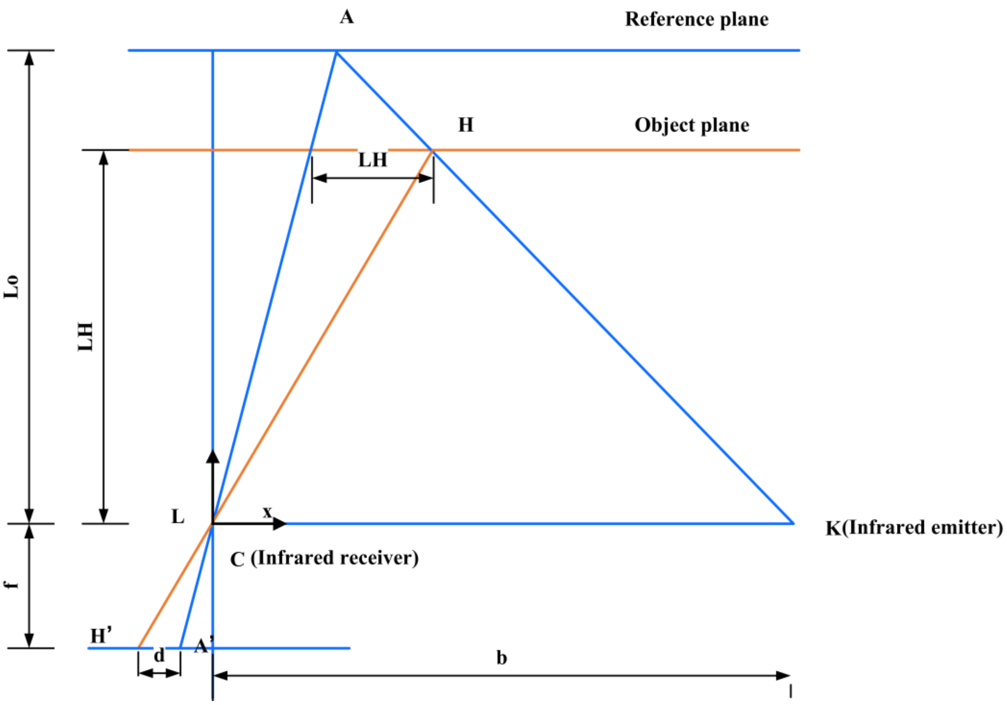

Figure 1: Schematic diagram of Kinect depth information measurement principle.

Let the reflection point of the infrared scattering spot at the reference plane point A in the imaging plane is recorded as $A^{'}$, and the point on the object plane H in the imaging plane is recorded as $H^{'}$. When $H^{'}A^{'}=d$ and the distance between the emitter and receiver is b, the focal length is recorded as f, the distance between the camera and the reference plane and the object plane are expressed as L_o, L_H, and the relationship can be obtained as shown in equation (1) for (2):

$$\begin{cases} \dfrac{D}{b} = \dfrac{L_o - L_H}{L_o} \\ \dfrac{d}{f} = \dfrac{D}{L_H} \end{cases} \tag{1}$$

$$L_H = \frac{L_o}{1 + \dfrac{L_o d}{fb}} \tag{2}$$

In order to make the obtained data more accurate, the camera color camera and infrared camera will be calibrated by checkerboard calibration at that time before the 3D reconstruction, as shown in Figure 2 for the 3D output of the relative positions between the checkerboard and the camera. The colored quadrilateral represents the board calibration plate at different positions, and the coordinates $O - x_c y_c z_c$ are the reference coordinate system of the Kinect camera, and the location of the optical center is the origin of the coordinate system.

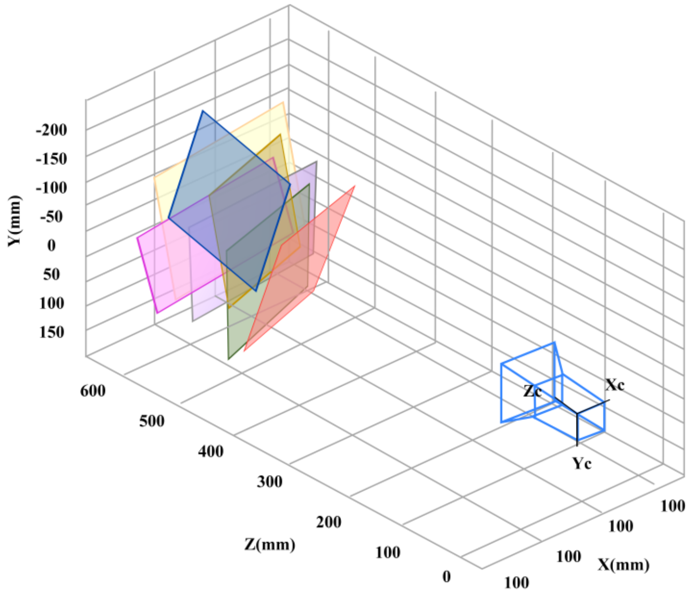

Figure 2: Relative poses between Kinect camera lens and checkerboard calibration board.

After the calibration is completed, the camera position needs to be estimated and the motion trajectory needs to be described accordingly, and the large region of the cavity needs to be handled by fusing geometric and image information. Assuming that the corresponding point set exists in the large point cloud has been matched and mapped on two frames, respectively, as $Q = \{q_1, q_2, ..., q_n\}$, $Q^{'} = \{q^{'}_1, q^{'}_2, ..., q^{'}_n\}$, the rotation between camera positions 1 and 2 is denoted as R , and the translation between them is denoted as W , the relationship is shown in (3):

$$\forall i, q_i = Rq^{'}_i + W \tag{3}$$

where the parameters R and W can be represented by the matrix B, as shown in (4):

$$B=\begin{pmatrix} R_{3\times 3} & W_{3\times 1} \\ 0 & 1 \end{pmatrix} \tag{4}$$

Then the camera position can be described by equation (5):

$$B_1\cdot B_2=\begin{pmatrix} R_1 & W_1 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} R_2 & W_2 \\ 0 & 1 \end{pmatrix}=\begin{pmatrix} R_{R_2 1} & R_1 W_2+W_1 \\ 0 & 1 \end{pmatrix} \tag{5}$$

In this method, the points in the two frames are matched by matching the points in the current depth frame with the acquired projected point image of the previous model frame, and the error between the two points can be calculated by point-to-plane. When the error between the current frame and the projected surface vertices is minimized, the parameter δ can be determined, as shown in Equation (6):

$$E_{icp}=\sum_h \left\| (v^h-\exp(\hat{\delta})Tv_n^h)n^k \right\|^2 \tag{6}$$

Where the vertex vector of the h in the frame with sequence number n is described as v_n^h, the corresponding vertex vector and normal vector are v^h and n^k respectively, and the transformation estimate between the current frame and the model frame is denoted as T, and its transformation matrix to the model frame is described as $\exp(\hat{\delta})$. The expression of the parameter δ with respect to the camera rotation and translation matrices is shown in (7):

$$\begin{cases} \delta=\begin{bmatrix} \rho \\ \varphi \end{bmatrix} \\ \hat{\delta}=\begin{bmatrix} \hat{\varphi} & \rho \\ 0^T & 0 \end{bmatrix} \end{cases} \tag{7}$$

Determining the camera rotation matrix at a given moment according to the definition of phase correlation enables to obtain the corresponding 3D vector φ, whose corresponding antisymmetric matrix satisfies Equation (8):

$$\hat{\varphi}=\begin{pmatrix} 0 & -\varphi_3 & \varphi_2 \\ \varphi_3 & 0 & -\varphi_1 \\ -\varphi_2 & \varphi_1 & 0 \end{pmatrix}=\dot{R}\cdot R^T \tag{8}$$

Taylor's first order expansion with initial value of I ,which yields

$$R=\exp(\hat{\varphi}) \tag{9}$$

And translate the vector $W=J\rho$,then we can get the equation (10)

$$\exp(\hat{\delta})=\begin{bmatrix} \exp(\hat{\varphi}) & J\rho \\ 0^T & 1 \end{bmatrix}=\begin{bmatrix} R & W \\ 0^T & 1 \end{bmatrix} \tag{10}$$

The error is linearized and the result is shown in Equation (11):

$$E_{icp} \approx \sum_{h} \left\| (v^h - (I+\hat{\delta})Tv_n^h)n^k \right\|^2 = \sum_{h} \left\| (v^h - Tv_n^h)n^k - \hat{\delta}Tv_n^h n^k \right\|^2 \tag{11}$$

By solving the SVD method, the optimal result of the moment can be obtained, and the rotation and translation matrices and the corresponding external parameters are derived, and the camera's current position is determined.

In order to improve the accuracy of the camera pose estimation, the raw data obtained by using the sensor by virtue of the fused image information estimation method can be used to obtain the environmental depth information, and then minimize the error and obtain the optimal pose by the optical flow method. The error determined by the weighting method is shown in Equation (12) as follows:

$$E = E_{icp} + w_r E_r \tag{12}$$

where the error minimization is denoted as E_r and the image information and geometric information weights are denoted as w_r .

3.2 Virtual Reality-Based Three-Dimensional Sound Technology Implementation Method

Film and television special effects not only need to enhance image information, but also need to enhance the viewer's sense of reality and immersion through other senses. The most common is to enhance the viewer's perception of the mixed environment through sound information, while weakening the brain's dependence on vision and reducing the immersion requirements in terms of visual information, as shown in Figure 3 for the hardware architecture structure of a 3D sound system based on virtual reality technology. Before 3D sound is rendered through the system, 3D registration of the sound source is required, i.e., real-time localization of the sound source, which is able to change the relative sound source direction and position according to the viewer's position and posture in the real world, and is the key part of the whole system.

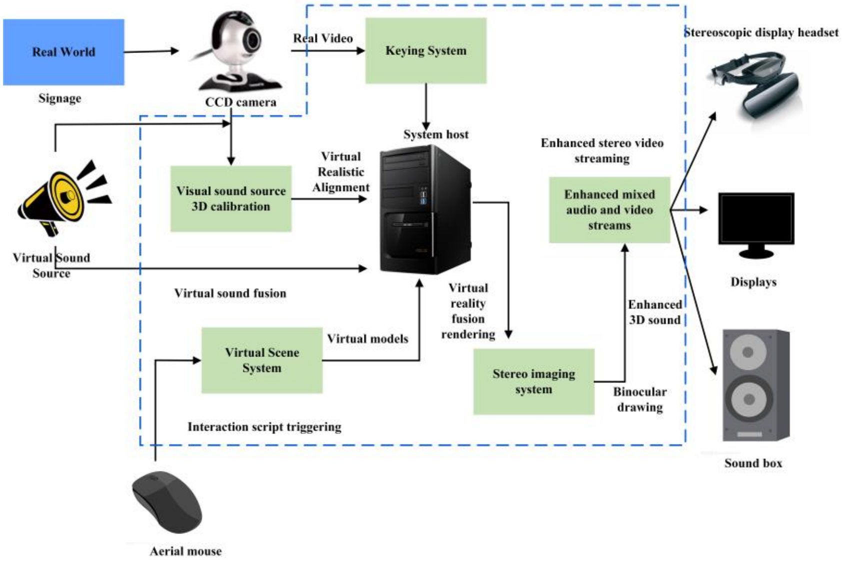

Figure 3: The hardware architecture structure of the 3D sound system based on virtual reality technology.

The 3D registration of the sound source requires first obtaining the corresponding color image based on the viewer's preset threshold and transforming it into a binary black and white image for connectivity domain analysis, from which all quadrilateral candidate matching regions are determined. The identified candidate regions are matched with the templates in the template database accordingly, and if the matching is completed a representation is identified. The deformation based on this representation can calculate the position and pose of the who-shin-na estimate relative to the already identified representation, after which the 3D registration of the virtual sound source is completed by the 3D transformation matrix. In the three-dimensional registration needs to be the corresponding transformation of the coordinates of the sound source, set the origin of the coordinate system is the logo coordinates of the sound source, the positive direction is noted as the horizontal axis direction, the world coordinates and logo coordinates between the overlap relationship. In the known relative position and direction between the viewer and the camera, the coordinates of the sound source are transformed.

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} R & W \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} = C \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} \tag{13}$$

where the orthogonal 3×3 matrix is represented as R , the rotation matrix between the camera and the sign coordinates, and the 3D translation vector is represented as W , the translation matrix between the two.

Let a point in the camera coordinate system be $P(x_c, y_c)$, its projection in the screen coordinate system be $P^{'}(m,n)$, the image pixel coordinates be (m,n) , and the physical size of each pixel in the direction of the x and y axes be dx, dy , respectively, as shown in Equation (14) as the transformation equation between the camera and screen coordinate systems:

$$Z_c \begin{bmatrix} m \\ n \\ 1 \end{bmatrix} = \begin{bmatrix} a_x & 0 & m_0 & 0 \\ 0 & a_y & n_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = P \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} \tag{14}$$

Among them, $a_x = f/dx, a_y = f/dy$.

After the derivation it is obtained that

$$Z_c \begin{bmatrix} m \\ n \\ 1 \end{bmatrix} = PC \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} = T \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix} \tag{15}$$

4 RESEARCH ANALYSIS AND DISSECTION

The experimental part is chosen to use the public dataset in TUM for testing. The special effects 3D spatial reconstruction model based on virtual reality technology in this paper is a combination of geometric information estimation and image grayscale information estimation, and the errors of both will be calculated based on the superposition of the weighting method, so different values of the weight coefficients will have different effects on the bit pose estimation results. According to the relevant information, the value range of the weight coefficients in this paper is [0,0.14]. In the experimental process, two datasets were selected in the TUM dataset for the corresponding test, which contained the RGB and depth information of the scene, and the two were correlated by timestamps. The trajectories of the two RGB-D cameras obtained according to the bit-pose estimation algorithm above and the depth data of the actual camera motion trajectories in TUM will be compared. The error results of fr1/xyz group data and fr1/room group data with different values of weighting coefficients are shown in Figure 4.

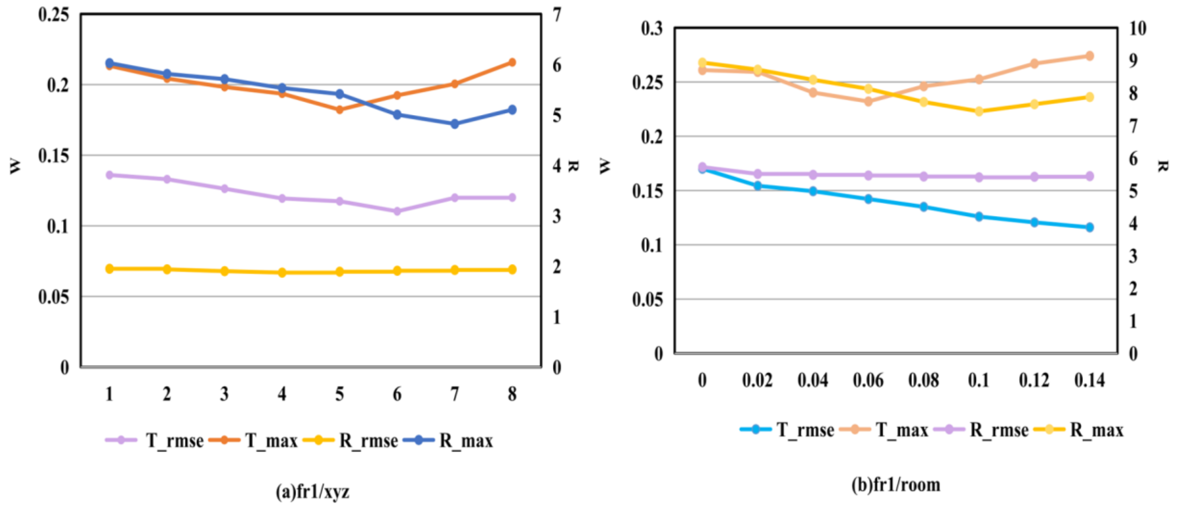

Figure 4: Error results of fr1/xyz group data and fr1/room group data with different values of weighting coefficients.

In Figure 4, W_rmse and W_max depict the root-mean-square error and the maximum error value of the translation part, and R_rmse and R_max depict the root-mean-square error and the maximum error value of the rotation part, respectively. From the experimental results, it can be obtained that the fusion of geometric and grayscale information has a corresponding effect on the camera pose estimation when the values of the weight coefficients are changed, and the results obtained after adding the depth information rotation and translation errors are smaller than those obtained by the previous pose estimation methods, which means that the introduction of depth data information improves the accuracy of pose estimation. According to the experimental requirements and data results, this paper considers that the accuracy of the obtained results is optimal when the weight coefficient takes the value of 0.1.

As shown in Figure 5, the comparison results of camera pose estimation and depth information camera pose trajectory after confirming the values of weight coefficients are taken. The results in the figure show that the relative errors of camera poses shown in the two different datasets fluctuate within a certain error range, and the difference of their fluctuation values in the fr1/room dataset is relatively larger and the fluctuation magnitude is higher than that of the other dataset results. However, overall, the relative error range of the camera poses for comparing each other does not exceed 0.26m, showing a better accuracy of the pose-estimation. In order to verify the accuracy of the model in global film and television special effects production, the absolute error comparison results of three different optimization algorithms in the same data set are shown in Figure 6, where the optimization algorithm of this model is geometric image fusion combined with loopback algorithm, and the other two comparison algorithms are the algorithm without any optimization and the optimization algorithm with only geometric and image information fusion.

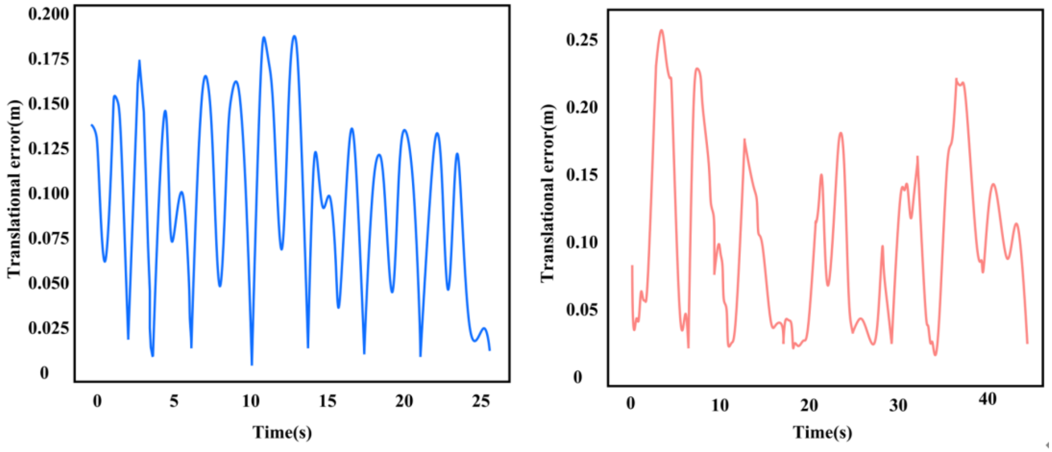

Figure 5: Comparison results of camera pose estimation and depth-informed camera pose trajectory.

The data in the figure show that the absolute error of the optimization algorithm of this model is lower than the other two algorithms, whether it is the extreme value, the middle value or the mean square error. This indicates that the model optimization algorithm in this paper effectively reduces the sentence pair error, significantly improves the accuracy of the model, and shows better stability, which can ensure the optimality of the experimental results.

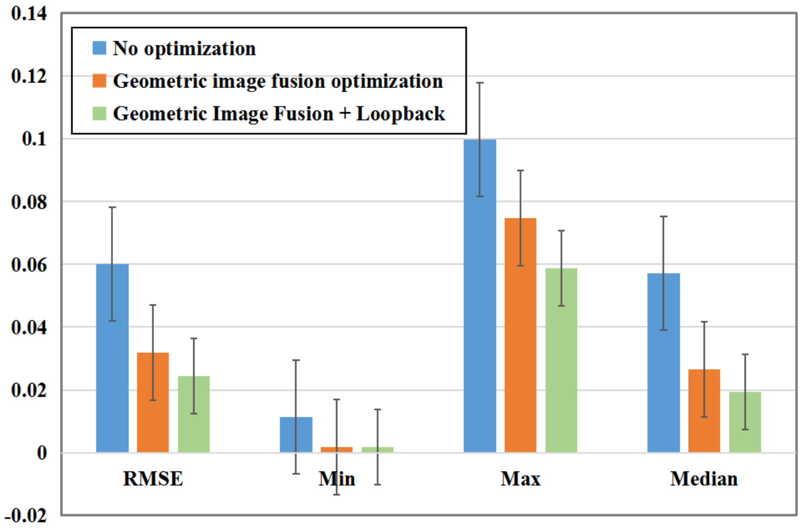

Figure 6: Comparison results of absolute errors of three different optimization algorithms in the same data set.

In order to further verify the optimization effect of the model in this paper, the trajectories generated by the positional estimation model without any optimization are compared with those generated by the positional estimation model, as shown in Figure 7. The results in the figure show that there is a large trajectory error in the global trajectory before the optimization is performed for, and after the optimization, the global trajectory is obviously corrected.

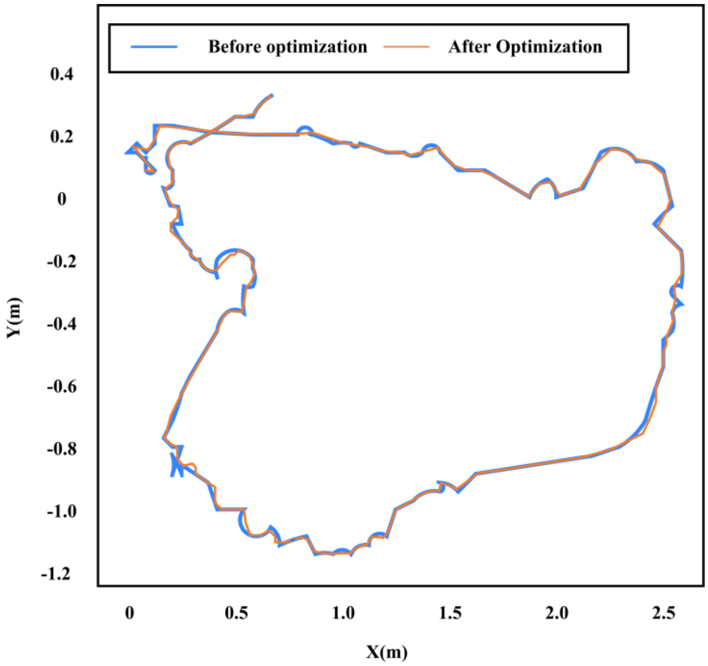

Figure 7: Comparison results before and after global trajectory optimization.

The 3D space reconstruction model of virtual reality technology refers to computer graphics and related technologies. Describe and restore objects, scenes, human bodies, etc. in three-dimensional space through virtual mathematical models. Ultimately, it is presented to users through virtual reality devices such as headsets, controllers, etc. This model has the characteristics of strong realism, high degree of automation, and low cost.

5 CONCLUSION

This article proposes research on digital film and television special effects production based on virtual reality technology. By combining geometric image information and image grayscale information estimation, a camera pose estimation algorithm for 3D reconstruction models is established, and a loop back algorithm is introduced for optimization. In addition, this article also introduces a 3D virtual sound source in the production of film and television special effects, and enhances the effect of sound source position transformation through 3D registration. The experimental results show that compared with other algorithm models, our model can effectively reduce position estimation errors and maintain good stability after determining the weight coefficients. At the same time, compared with models without any optimization of pose estimation, this model can effectively correct global trajectories, improve the stereoscopic display effect and realism of film and television special effects. The higher accuracy of pose estimation models can also provide a stable technical foundation for 3D registration of 3D sound sources, thereby improving the overall digital film and television special effects production effect, enhancing the 3D visual effect and sound perception of special effects.

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REFERENCES

[1] Bacharidis, K.; Sarri, F.; Ragia, L.: 3D building façade reconstruction using deep learning, ISPRS International Journal of Geo-Information, 9(5), 2020, 322. https://doi.org/10.3390/ijgi9050322

[2] Baía, R.-A.; Ashmore, M.: From video streaming to virtual reality worlds: an academic, reflective, and creative study on live theatre and performance in the metaverse, International Journal of Performance Arts and Digital Media, 18(1), 2022, 7-28. https://doi.org/10.1080/14794713.2021.2024398

[3] Carpio, R.; Birt, J.: The role of the Embodiment Director in virtual reality film production, Creative Industries Journal, 15(2), 2022, 189-198. https://doi.org/10.1080/17510694.2021.2017634

[4] Cui, Q.; Sharma, A.: Digital media animation control technology based on maya, Recent Advances in Electrical & Electronic Engineering (Formerly Recent Patents on Electrical & Electronic Engineering), 14(7), 2021, 735-743. https://doi.org/10.2174/2352096514666210805160749

[5] Fischer, J.: Traversing the Boundary of the Screen: Contextualizing the Influence of Cinema and Virtual Reality in Artificial Environments, Cinergie–Il Cinema e le altre Arti, 1(19), 2021, 105-120. https://doi.org/10.6092/issn.2280-9481/12227

[6] Kerr, J.; Gillian, L.: Augmented reality in design education: Landscape architecture studies as AR experience, International Journal of Art & Design Education, 39(1), 2020, 6-21. https://doi.org/10.1111/jade.12227

[7] Liu, G.: Influence of digital media technology on animation design, In Journal of Physics: Conference Series, 1533(4), 2020, 042032. https://doi.org/10.1088/1742-6596/1533/4/042032

[8] Liu, Z.-N.; Cao, Y.-P.; Kuang, Z.-F.; Kobbelt, L.; Hu, S.-M.: High-quality textured 3D shape reconstruction with cascaded fully convolutional networks, IEEE Transactions on Visualization and Computer Graphics, 27(1), 2019, 83-97. https://doi.org/10.1109/TVCG.2019.2937300

[9] Luangrath, A.-W.; Peck, J.; Hedgcock, W.; Xu, Y.: Observing product touch: The vicarious haptic effect in digital marketing and virtual reality, Journal of Marketing Research, 59(2), 2022, 306-326. https://doi.org/10.1177/00222437211059540

[10] Pepe, M.; Costantino, D.; Restuccia, G.-A.: An efficient pipeline to obtain 3D model for HBIM and structural analysis purposes from 3D point clouds, Applied Sciences, 10(4), 2020, 1235. https://doi.org/10.3390/app10041235

[11] Song, Q.; Wook, Y.-S.: Exploration of the application of virtual reality and internet of things in film and television production mode, Applied Sciences, 10(10), 2020, 3450. https://doi.org/10.3390/app10103450

[12] Xu, C.: Immersive animation scene design in animation language under virtual reality, SN Applied Sciences, 5(1), 2023, 42. https://doi.org/10.1007/s42452-022-05263-x

[13] Wilmsherst, J.; Mackay, A.: Utilizing virtual reality and three-dimensional space, visual space design for digital media art, Global Media Journal, 20(56), 2022, 1-3. https://doi.org/10.36648/1550-7521.20.56.334

[14] Yang, B.; Liu, B.; Zhu, D.; Zhang, B.; Wang, Z.; Lei, K.: Semiautomatic structural BIM-model generation methodology using CAD construction drawings, Journal of Computing in Civil Engineering, 34(3), 2020, 04020006. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000885

[15] Yu, Y.; Hao, T.; Zhang, H.: Research and practice of hybrid teaching mode of “film and television production technology and art” course based on OBE concept, Creative Education, 12(9), 2021, 2066-2073. https://doi.org/10.4236/ce.2021.129158

[16] Zeng, R.: Research on the application of computer digital animation technology in film and television, In Journal of Physics: Conference Series, 1915(3), 2021, 032047. https://doi.org/10.1088/1742-6596/1915/3/032047

[17] Zhao, J.; Zhao, X.: Computer-aided graphic design for virtual reality-oriented 3D animation scenes, Computer-Aided Design and Applications, 19(1), 2022, 65-76. https://doi.org/10.14733/cadaps.2022.S5.65-76