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Reconstruction of Visual Appeal and Renewal of Dynamic Environments: Computational Methods and Innovative Strategies in the Future-oriented Digital Transformation of Heritage Museums

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ABSTRACT

In the context of the digital economy driven by the Internet of Everything, the dissemination of cultural heritage is facing the challenge of transitioning from traditional to digital media. The study develops an introduction to the visual SLAM system, models the binocular camera configuration and the indoor and outdoor dense 3D reconstruction process, and designs a complete set of algorithms based on the calibration of the actual binocular camera, image correction, binocular stereo matching algorithm (S-ELAS), and real-time dense point cloud 3D reconstruction. Based on the real laboratory scene, the original ELAS algorithm is compared with the improved method for experiments, and the results show that the mean value of the deviation of the optimized S-ELAS algorithm is -0.046m, and the algorithm accuracy is remarkable. Then a virtual cultural relics museum based on the combination of visual S-ELAM system and VR technology is designed to realize close interaction with S-ELAS stereo matching algorithm. In order to test the performance of the designed cultural relics museum system, the users are firstly acclimatized, and then the screened users are tested to experience the virtual museum system, and the MOS scores are made after the test. The MOS scores show that the virtual cultural relics museum system has better interactivity and experience.

Keywords: binocular vision, virtual technology, interaction, digital transformation

1. Introduction

Cultural relics are the important heritage carrying the history, culture and spirit of mankind, and are the witnesses, witnesses and survivors of civilization, as well as the disseminators of culture, which is the “living history”. As an important place for cultural heritage, museums carry rich historical, cultural and artistic heritage, and play an important role in cultural propaganda and historical cognition of the

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society [1-4]. However, traditional museums face many challenges, including the homogenization of exhibition display forms, the increasing difficulty of cultural relics protection, and the lack of audience participation [5-7]. With the rapid development of information technology, digital transformation has become one of the key paths for museums to cope with the challenges and improve the level of exhibition and conservation [8]. Digital transformation uses information technology means to digitally process the museum's cultural relics, exhibitions, education and other contents, and realizes a new presentation and protection of cultural relics and exhibitions with the help of the Internet, virtual reality and other technical means [9-11]. To realize the digital transformation of museums is to take digital technology as the core and to meet the audience experience as the goal, and to make a new positioning and upgrade the function, structure and operation concept of museums [12-13]. Through the collection of museum collections, storage, research, display, dissemination of a full range of information technology innovation, and then effectively promote the museum of cultural relics exhibition and management and operation concept transformation, comprehensively enrich the public's cultural life to improve the museum's management efficiency and quality of service, to achieve a win-win situation for the museum's economic and social value [14-17]. In this context, in-depth discussion of the calculation methods and innovative strategies of digital transformation of museums, analyze the advantages and challenges of digital transformation, and provide theoretical reference and practical guidance for the future development of museums [18-20].

Digital transformation has brought brand new development opportunities for museums. First of all, in terms of exhibitions, through digital transformation, than irrelevant can realize virtual reality and interactive experience, which greatly enriches the visitor's experience. Lee, H. et al. showed that the combination of virtual reality technology and museum tours can provide visitors with an immersive sense of participation, and from the four experience economic domains verified that the museum VR experience has a very large impact on the willingness of tourists to visit the museum, and has an excellent competitive advantage [21]. Shehade, M. et al. look beyond the visitor's perspective and explore the impact of virtual reality experiences on professionals during the digital transformation of museums, providing recommendations for the design and development of future VR museums from a more professional and highly critical perspective [22]. Carvajal, D. A. L. et al. use 3D modeling and texturing techniques to create two virtual environments for the museum virtual environments for cultural heritage dissemination, which have visualization and interactive features that promote the development of virtual museums [23]. In virtual museums, visitors can observe and interact with the displayed artifacts in depth at any time, which is conducive to understanding the relevant history behind the artifacts.

Secondly, in terms of heritage conservation, digital transformation provides a variety of means for heritage conservation. Puspita, A. A. et al. used photogrammetric 3D scanning methods to convert museum artifacts into digital visual data. The alternative application of relevant digital data not only helps in heritage conservation, but also supports design science as well as education and teaching [24]. Pache de Faria, C. et al. examined the digital conservation of textile artifacts in museums, and the use of capture and reproduction techniques to dematerialize historical costumes in museums into digital objects is a simple, economical and feasible solution for the conservation of artifacts [25]. Vuković, M., et al. outlined a process of practicing the digital conservation of artifacts in archaeological museums by using relevant image processing techniques with 3D model modeling techniques for the Digital translation of artifacts allows most of the artifacts affected by the earthquake to be displayed in their entirety to visitors [26]. Digital technology for cultural relics to establish a digital archive, can be accurate management and protection of cultural relics, greatly improving the efficiency and quality of cultural relics protection. In summary, the digital transformation for the development of museums to bring many advantages and overflow, it is worthwhile for scholars to conduct in-depth research.

Firstly, the basic framework theory of vision SLAM system is introduced, and the overall algorithm flow of a 3D reconstruction optimization algorithm based on binocular vision is designed. It contains the assembly and calibration of binocular camera, binocular stereo matching algorithm and optimization as well as 3D reconstruction and point cloud optimization algorithm, and finally conducts experimental validation, data set acquisition, experimental parameter setting and analysis of experimental results. Then the visual SLAM and virtual technology is used to design the virtual heritage museum to realize the digital transformation of the museum. In order to test the performance of the developed virtual heritage museum system, users experience the system and score the MOS after the test.

2. 3D Virtual Reconstruction of Cultural Relics Museum Based on Visual SLAM System

Visual SLAM is one of the core tools for generating VR content. The goal of visual SLAM is to accurately estimate the camera's own pose transformation and recover the 3D structure of the environment in an unknown environment, relying only on image input. The process does not rely on other sensors, and analyzes the camera's motion trend solely through image feature matching, based on which it performs 3D reconstruction and generates sparse/dense reconstruction results in point cloud or mesh representation. Specifically, the monocular SLAM system achieves the “key frame” constraints between camera positions by tracking the key point features between images; then based on these inter-frame relationships, the beam leveling algorithm is used to perform global optimization, which improves the accuracy of the recovery of 3D point positions and camera trajectories. In addition, some semi-dense methods can generate higher-quality 3D reconstruction at real-time speed with the assistance of depth data acquired by binocular RGB-D cameras; some learning-based dense reconstruction frameworks, such as unstructured multi-view stereo depth inference (MVSNet), can automatically and completely recover the surface details from a set of images by using matched features extracted from CNNs to realize the fine environment reproduction.

2.1. Basic framework of visual SLAM system

2.1.1. Visual SLAM system modeling. Mathematical modeling of a vision SLAM system can provide a better understanding of the operation of the system. Suppose a mobile robot carries a camera sensor to move in an unknown real environment, the camera sensor collects image data in the real scene, assuming that the moment of collection is $t=1,2,\ldots\ldots,k$, then the collected image can be viewed as a discrete motion, at this time, the robot corresponds to the moment of movement of the position of the position of the robot is $x_1,x_2,\ldots\ldots,x_k$, assuming that there are N map waypoints in the environment as $y_1,y_2,\ldots\ldots,y_N$, with the movement of the robot, the camera sensor at each moment will collect the some of the map waypoints at each moment as the robot moves. In order to better describe how the robot autonomously moves and senses the environment in an unknown environment, the entire process is described using the observation equation and the equation of motion.

$$x_k = f\left(x_{k-1}, u_k, w_k\right) \tag{1}$$

$$z_{k,j} = h\left(y_j, x_k, v_{k,j}\right) \tag{2}$$

Where in the motion equation (1), u_k is the input from the camera sensor and w_k is the noise data. In the observation equation (2), $z_{k,j}$ is the observation data and $v_{k,j}$ is the noise in the observation data.

2.1.2. Visual odometers. The task of Visual Odometry (VO) is to estimate the motion trajectory of the camera based on the acquired image frame data [27]. The methods currently used in visual odometry can be divided into the direct method and the feature point method, in which the feature point method is the more mainstream method in visual odometry due to its stability and insensitivity to light and other advantages, the workflow of the feature method is shown in Fig. 1.

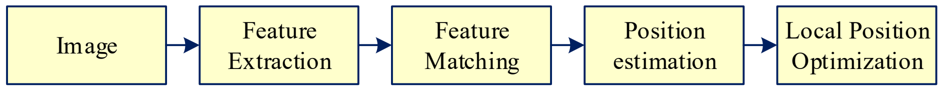

Fig. 1. Feature point method workflow path

Among them, the pose estimation is the most central part of the feature method, which mainly includes the pair-polar geometry algorithm for 2D-2D point matching, the nearest point iteration ICP algorithm for 3D-3D point matching, and the PnP algorithm for 3D-2D point matching. Among them, the pair-polar geometry algorithm can solve the pose using only more than 8 matched pairs of feature points in two images, but there is the problem of pure rotation of initialization and scale uncertainty; the ICP solves the pose with a set of well-matched 3D points, in which the acquisition of the depth is greatly affected by the depth sensor; and the PnP estimates the camera motion by using n 3D points and the corresponding pixel coordinates, which can be obtained with fewer pairs of matched 3D points. PnP utilizes n 3D points and the corresponding pixel coordinates to estimate the camera motion, which can obtain a better position estimation with fewer pairs of points.

2.1.3. Back-end optimization. For a long period of time due to the image frame containing noise, feature point mismatch and other factors, the visual odometry estimates of the camera trajectory and map and the actual motion trajectory and map inevitably have errors, and the error will be accumulated over time, the purpose of the back-end optimization is to make the error reduced, as far as possible to get the global consistency of the trajectory and map. Currently, back-end optimization can be divided into Extended Kalman Filter (EKF) and graph-based optimization, in which EKF is based on the assumption of Markovianity, i.e., the state of the current moment is only related to the previous moment, and the state of the previous moments and observations are irrelevant, so the method based on EKF is unable to solve the problem of data correlation in non-adjacent moments. In addition, EKF only does linearization once, which leads to nonlinear error at each iteration, and the storage required at runtime is very huge, which is not applicable in large-scale real-world scenarios.

In order to solve the above shortcomings of EKF, graph optimization optimizes the observation points and the position of the camera at the same time, and this method is called beam method leveling.BA optimization problem belongs to the nonlinear optimization problem, which is intuitively to solve the optimization variables along the direction of the gradient descent so as to minimize the error and the optimization variables. The idea of the BA optimization problem is as follows: assume that in the space of the real scene consists of countless three-dimensional spatial points, these spatial points emit light in different directions, then the camera plane in different positions will receive these rays and thus become a pixel or a feature point on the imaging plane, you can adjust the position of the camera and the position of the 3D spatial points, so that these rays eventually converge in the optical center of the camera, then this time to solve the position of the camera that is the optimal solution.

2.1.4. Loopback detection. The main purpose of loopback detection is to eliminate the cumulative error in the system due to position estimation errors. Loopback detection identifies whether the camera has been to this position before, and when it is successful, it provides this constraint to the back-end optimization to eliminate the accumulated errors, and then get a globally consistent trajectory and map.

Loopback detection can be realized in two ways, one is based on the geometric relationship of the odometer, but it is difficult to continue to work when the odometer error is large; the second is based on the similarity of image frames, as long as the similarity between the image frames can be detected to reach the set threshold, loopback detection can be realized, independent of the influence of other modules in the system, is currently a more mainstream method. The similarity of the images can be described using bag-of-words model, whose main steps are: first determine the concept of words in the scene, such as “person, sofa, car”, i.e., to form a “dictionary”; and then describe each image with the words, and convert the images into vectors; Finally, we compare the degree of similarity between the descriptions of the two images.

2.1.5. Map construction. Map construction can be roughly divided into two kinds, one is topological map, the map form only considers the connectivity between nodes, ignoring most of the details of the map, often applicable to navigation and path planning. The second is metric maps, which consider the position of objects in the map. In visual SLAM, maps are mostly represented by point clouds, which can be categorized into sparse, semi-dense and dense maps according to their sparsity.

2.2. Optimization of 3D reconstruction of museums based on binocular vision

2.2.1. Binocular camera assembly and calibration. The deployment of the binocular camera [28] was carried out first, the actual binocular camera used was found to display a composite image after use, which was divided in half from the middle for the images of the two monocular cameras, respectively, and the binocular camera calibration required the input of two separate streams of images, hence the need for the image segmentation of the binocular camera as shown in Fig. 2.

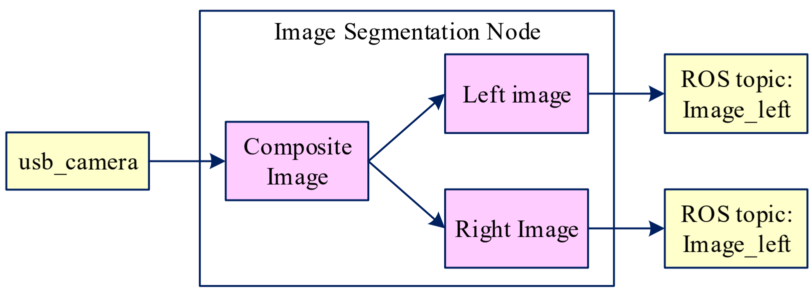

Fig. 2. Binocular camera image segmentation

Next, the calibration of the binocular camera is started. The calibration process is to solve the internal parameter K and the aberration coefficient D of the left and right cameras themselves, and at the same time to get the relative positional relationship between the two, i.e., the external parameter, which is generally the transformation relationship from the left camera to the right camera using the rotation matrix R and the translation vector t. It is necessary to compute these parameters through experiments and different data acquisitions. The calibration formula is the camera imaging principle, which uses the transformation between the world coordinate system and the image coordinate system to obtain the above parameters. Taking the left camera coordinate system as the world coordinate system, the relationship between the two cameras is as follows:

$$R = R_r\left(R_l\right)t \tag{3}$$

$$t = t_r - Rt_l \tag{4}$$

Where R and t are the external parameters to be computed, R_r, R_l and t_l, t_r are the rotation matrix and translation vectors of the left and right cameras, respectively.

The study mainly uses the Bouguet stereo correction method, whose main idea is that the rotation matrix is divided into two parts r_1 and r_1, which are used as synthetic rotation matrices for the left and right, respectively, with the aim of realizing the image planes as coplanar, which still need to be row-aligned. Then the matrix R_{rect} that can horizontally align and transform the left camera pole to infinity is computed:

$$R_{rect} = \left[e_1, e_2, e_3\right]^T \tag{5}$$

$$e_1 = \frac{t}{\|t\|} \tag{6}$$

$$e_2 = \frac{\left[-t_y t_x\right]^T}{\sqrt{t_x^2 + t_y^2}} \tag{7}$$

$$e_3 = e_1 \times e_2 \tag{8}$$

where t_x, t_y, and t_z are the translation vectors in each of the three directions, whereby the row alignment of the two cameras is realized by setting:

$$R_l = R_{rect} r_l \tag{9}$$

$$R_r = R_{rect} r_r \tag{10}$$

Above that, you can align the pictures taken by the binocular camera in parallel to get the ideal state.

2.2.2. Binocular Stereo Matching Algorithm. After preparing the binocular camera, i.e., the image, the parallax value needs to be computed using a binocular stereo matching algorithm, which translates into a depth map.

Firstly, the image is filtered to get the image composed of feature points, then the matching operation is performed and the corresponding points with high confidence values are selected as the support points of the image, and finally a Delaunay triangular grid is built for the selected points to get the probabilistic generative model. Suppose $S = \{s_1, s_2, \ldots\ldots, s_M\}$ is the set of selected support points, where each support point is denoted as $s_m = \left(u_m, v_m, d_m\right)^T$, where d_m is the parallax corresponding to $\left(u_m, v_m\right)$ points. Let $O = \{o_1, o_2, \ldots\ldots, o_N\}$ be the set of common observation points obtained from the image capture, and let $o_n = \left(u_n, v_n, f_n\right)^T$, where the first two are pixel values, the third is a feature vector, and $o_n^{(l)}$ and $o_n^{(r)}$ are the pairs of points corresponding to them in terms of the left image, and solve for the s random variable parallax d_n for a point $o_n^{(l)}$ in the left image, assuming that the joint distribution probability for a given parallax d_n can be decomposed as:

$$p\left(d_n, o_n^{(l)}, o_n^{(r)}, S\right) \propto p\left(d_n \mid S, o_n^{(l)}\right) p\left(o_n^{(r)} \mid o_n^{(l)}, d_n\right) \tag{11}$$

The formula can be called the prior probability, with $p\left(d_n \mid S, o_n^{(l)}\right)$ being the prior value and $p\left(o_n^{(r)} \mid o_n^{(l)}, d_n\right)$ being the likelihood probability. The ultimate goal is to use Bayesian inference to solve for the posterior probability density of the left parallax map given the set of support points and the right view, and then estimate the parallax by maximizing the posterior probability density:

$$d_n^* = \arg\max p\left(d_n \mid o_n^{(l)}, o_1^{(r)}, \ldots, o_N^{(r)}, S\right) \tag{12}$$

In addition, for the void area, set its range size th, when greater than the threshold, need to be designed to select the surrounding reliable value of the calculation for the void filling, assuming that an invalid point of the horizontal direction of the left and right sides of the parallax value of d_l and d_r its difference formula is as follows:

$$d = \begin{cases} \dfrac{d_l + d_r}{2} \\ \min(d_l, d_r) \end{cases} \tag{13}$$

Where y is a set depth threshold, greater than which indicates depth discontinuity. And the above improved ELAS algorithm is named S-ELAS (i.e., Stereo and Soft), which is more applicable to the actual binocular image and smooth depth map calculation method.

2.2.3. 3D point cloud reconstruction and optimization. After obtaining the parallax map, the point cloud 3D reconstruction can be started, and the detailed steps of adding a separate thread for dense 3D reconstruction in ORB-SLAM3 [29] with binocular camera were designed and implemented by ourselves, and the detailed algorithm steps are shown in Figure 3.

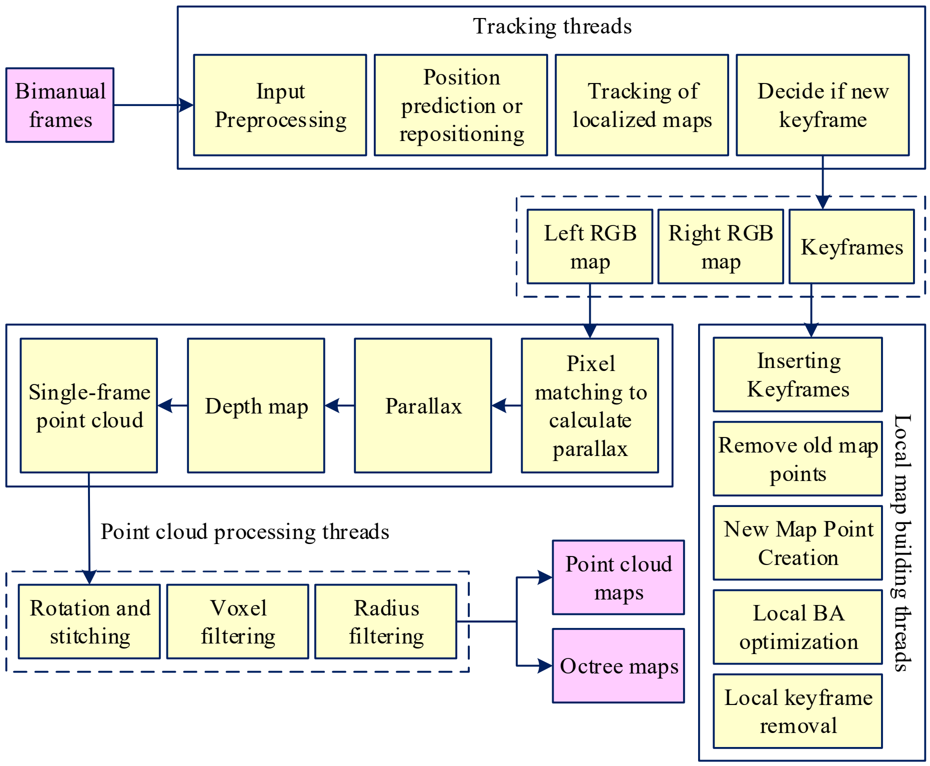

Fig. 3. Algorithm step

The tracking thread and the local mapping thread are algorithmic threads that already exist in ORB-SLAM3, and the point cloud processing thread is a separately added part, which is mainly responsible for the 3D reconstruction of the point cloud, and its relationship with the above two threads is shown in Figure. The specific step is to get the parallax map, and then convert it to depth map through the formula (11), in which the unit of parallax map is pixel, and the unit of depth map is usually mm.

$$depth = \frac{bf}{disp} = \frac{(f * baseline)}{disp} \tag{14}$$

Where $depth$ is the depth map to be computed, f is the camera focal length, $baseline$ is the baseline distance of the binocular camera, and $disp$ is the parallax map previously obtained. After obtaining the depth, a point cloud is created for the pixel points on the photo, assuming a pixel point (u,v) on the image, which is converted to a 3D point $P=(x,y,z,b,g,r)$ in the point cloud, with six base parameters, which are the coordinate values in the world coordinate system and the color values, where the last three parameters can be directly assigned to the corresponding pixel point's color value, with the following coordinate values:

$$z = depth \tag{15}$$

$$x = \frac{(u - c_x) * z}{f_x} \tag{16}$$

$$y = \frac{(v - c_y) * z}{f_y} \tag{17}$$

Two main issues were identified during the point cloud reconstruction process, one for dynamic objects, which need to be optimized for removal during 3D point cloud reconstruction.

Longer as well as outdoor build when the point cloud size is larger compared to indoor and occupy too much memory, the program is easy to crash when subsequent rendering to the interface traversed. Therefore, we add outlier filter (also called radius filter) and voxel filter by our own design, and divide the point cloud into local and global point cloud, and finally generate high-resolution local point cloud and low-resolution global point cloud.

2.3. SLAM 3D scene reconstruction experiment results and analysis

2.3.1. Description of experimental scenarios. In order to be able to more accurately evaluate the accuracy of the S-ELAS algorithm before and after the improvement, experiments were conducted on the public dataset and the actual indoor laboratory scenario, respectively. Firstly, the S-ELAS algorithm before and after the improvement is tested with the TUM subsequence of the public dataset and compared with the actual trajectory groundturth provided by it. Secondly, because indoor laboratories often contain different areas such as experimental areas and work areas, and store more equipment, more complex dimensions, and their scenes are more similar to manufacturing scenes such as logistics and warehousing, so based on the real laboratory scene, the original S-ELAS algorithm and the improved algorithm will be used to conduct 3D scene reconstruction comparison experiments, and to obtain the 3D scene reconstruction maps before and after the improvement of the S-ELAS algorithm (top view). In order to assess the accuracy and general applicability of the improved algorithm more comprehensively and accurately through a combination of quantitative and qualitative evaluation.

2.3.2. Quantitative evaluation criteria. In order to quantitatively analyze and compare the accuracy of the 3D scene reconstruction maps of the S-ELAS algorithm before and after the improvement, the root-mean-square error, median deviation, mean error, minimum error, maximum error, and standard deviation of the generated trajectories and the actual trajectories before and after the algorithm improvement are used to compare in the validation stage of the open dataset. In the real indoor scene experiments, 40 representative objects are selected in the scene for the comparison between the reconstructed object representation measurements and the real values, so as to quantify the accuracy of the improved S-ELAS algorithm.

2.3.3. Experimental results and analysis. In this experiment, the S-ELAS algorithm before and after the improvement are tested with the public dataset TUM subsequence freiburg3_long_office_household and compared with the actual trajectory groundturth provided by the dataset, and the results of the comparison of the three trajectories are shown in Figure 4. It can be seen that the improved algorithm is more consistent with the real trajectory compared with the original algorithm, while the trajectory composition is closed, but some of the trajectories still have deviations. Analysis of some images in the dataset is known to have overexposure problems, the optimization effect of MSRCR algorithm is not obvious, and the improved algorithm is more advantageous in general.

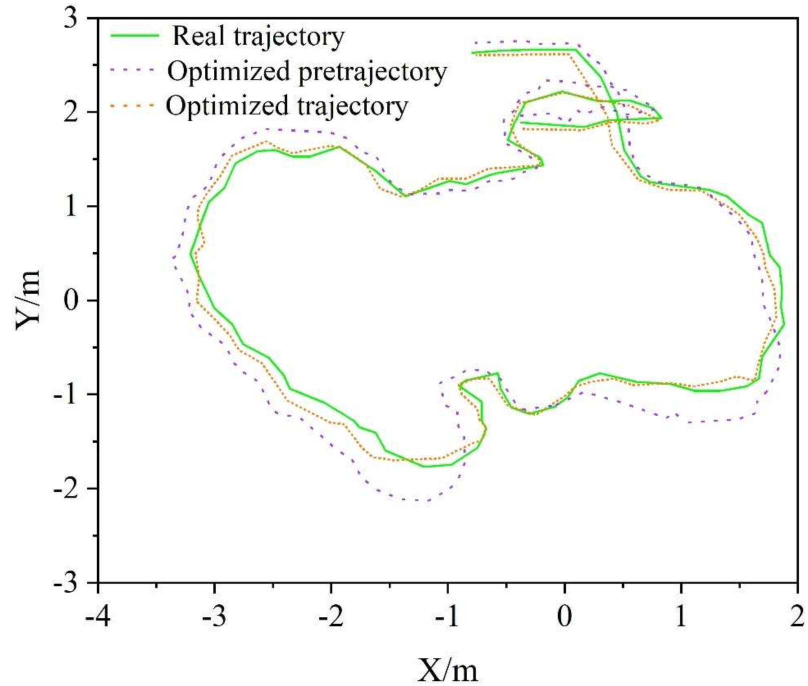

Fig. 4. The algorithm is improved before and after

Table 1 shows the error comparison data before and after the optimization of the algorithm, it can be seen intuitively that the improvement of the algorithm of the error compared to the original algorithm have different degrees of reduction, in which the error of the minimum value of the error Min, the standard deviation of the error of Std were reduced by 47.03% and 49.55%, respectively.

Table 1. The algorithm is improved and the error is compared(m)

Error category	Improvement	Improved	Contrast
S-ELAS	0.06414	0.04432	↓ 0.01982
Median	0.05296	0.05139	↓ 0.00157
Mean	0.0578	0.04427	↓ 0.01354
Min	0.01187	0.00653	↓ 0.00534
Max	0.14253	0.10128	↓ 0.04125
Std	0.03282	0.01686	↓ 0.01596

At the same time, in order to make the dense point cloud map created by the improved S-ELAS algorithm have more clear evaluation indexes, this experiment selects 40 representative objects within the scene for comparison between the reconstructed object representation measurements and the corresponding real values, and the actual comparison data are shown in Table 2.

From the table, we can intuitively see that there are more or less deviations between the reconstructed object characterization values and the real values of the actual objects in the 3D scene map, with the minimum deviation value of 0.003 m and the maximum deviation value of 0.525 m. Although there is a certain degree of deviation between the reconstructed values and the real values, the mean value of the deviation is -0.046 m, which is not difficult to show that the front-end and back-end improved S-ELAS algorithms are very useful in the tasks of reconstruction and feature point matching of the 3D scene map, the experimental data are shown in Table 2. It is easy to see that the improved S-ELAS algorithm at the front and back ends performs well in the tasks of 3D scene map reconstruction and feature point matching.

Table 2. The measured value of the object was reconstructed and the real value was compared (m)

Object number	Representation length		Deviation value	Object number	Representation length		Deviation value
	Measured value	True value			Measured value	True value	
1	0.381	0.37	0.011	21	0.641	1.058	-0.417
2	1.463	1.525	-0.062	22	0.554	0.555	-0.001
3	1.639	1.608	0.031	23	1.555	1.442	0.113
4	0.069	0.08	-0.011	24	0.933	0.854	0.079
5	2.541	2.507	0.034	25	0.333	0.537	-0.204
6	1.44	1.506	-0.066	26	0.058	0.055	0.003
7	3.598	3.508	0.09	27	0.456	0.508	-0.052
8	3.86	3.61	0.25	28	1.057	1.147	-0.09
9	0.989	1.01	-0.021	29	2.31	2.457	-0.147
10	1.012	1.109	-0.097	30	3.755	3.23	0.525
11	1.879	1.857	0.022	31	2.794	2.548	0.246
12	1.503	1.56	-0.057	32	1.755	1.955	-0.2
13	0.045	0.05	-0.005	33	2.991	2.54	0.451
14	0.426	0.518	-0.092	34	1.01	1.005	0.005
15	0.298	0.261	0.037	35	1.687	1.737	-0.05
16	1.332	1.209	0.123	36	2.464	2.566	-0.102
17	2.104	2.008	0.096	37	0.332	0.455	-0.123
18	2.88	2.955	-0.075	38	0.328	0.516	-0.188
19	3.648	3.506	0.142	39	1.964	2.008	-0.044
20	0.359	0.416	-0.057	40	2.237	2.539	-0.302

3. Digital museum based on visual SLAM and VR technology

3.1. Design thinking

3.1.1. Sorting out traditional elements of cultural heritage. The rich connotation, form and aesthetic characteristics of traditional elements of cultural heritage, as well as the values and meanings they carry, have enriched the various dimensions of cultural heritage museums to a certain extent.

In the process of digitization, the inheritance, decoding and reconstruction of traditional elements of cultural heritage are particularly important. In this process, it is necessary to extract representative cultural symbols from specific cultures based on the ethnicity and characteristics of cultural heritage, which can represent the essence of cultural heritage, and then derive works with strong cultural heritage colors based on them. The transformation of traditional elements of cultural heritage symbols focuses on the reconstruction of cultural heritage by using modern design language and expression, which involves in-depth understanding of and respect for the traditional elements of cultural heritage in terms of history, cultural background, techniques and other aspects.

3.1.2. Integration with modern technology. The application of cultural heritage in contemporary life needs to combine the two elements of science and technology and humanities, so as to preserve the humanistic atmosphere of traditional skills and to inject new vitality into cultural heritage by relying on modern science and technology. The traditional elements of the sorted cultural heritage are constructed into digital products. In order to preserve the core value of traditional elements in the digital environment, creators need to combine and present these elements in an innovative way.

Virtual reality technology provides a way to preserve cultural heritage, and combining virtual reality technology has several advantages: first, it enhances the interactive experience. Viewers can get an immersive experience through virtual reality technology, not only viewing the whole process of cultural heritage production, but also interacting with the virtual environment to enhance the audience's storytelling experience. Second, restore the craft production scene. With the help of virtual reality and three-dimensional software, cultural heritage production scenes and cultural activities can be reproduced, allowing the audience to better understand the history and cultural connotations behind, and enhancing the audience's sensory experience. Thirdly, innovative presentation forms. Cultural heritage is facing the dilemma of gradual loss of skills, through the application of virtual reality technology can attract the younger generation, and inject new vitality into cultural heritage.

3.2. Design Framework for Digital Display of Cultural Heritage

3.2.1. Demonstration System Functional Requirements Analysis. In order to explore the needs of users to visit the exhibits of cultural relics in the museum, from the user's visit process summarizes the necessary system functions of the display system. Through the analysis of user visiting behavior habits, found that the user in the see cultural relics, the first is the need to carefully understand the appearance of cultural relics, cultural relics in order to consider the safety of most of the time in the display cabinet, the user needs to watch around the display cabinet, when the display cabinet is designed to be connected to the junk or against the wall, want to see the full picture of the cultural relics can only choose to go around the counter in a circle, to the back of the display cabinet to watch or to give up watching the cultural relics of the other side, the second is the introduction of the artifacts The second point is the introduction of cultural relics are all in the form of text affixed to the bottom of the cabinet, need to read when you need to get close to watch, and when you want to understand the use of cultural relics related to the scene, and the production process, you can only refer to the online information, etc., in the Museum taking into account the use of the exhibition hall area and can not be a comprehensive display of cultural relics of the information. Therefore, there is a great degree of incomplete and inconvenient for users to obtain relevant information.

The application of mixed reality technology is also an expansion of the museum's information display, solving the problem of incomplete information introduction caused by many practical factors such as spatial location.

3.2.2. Display system task flow analysis. Users open the system for a complete viewing task process is as follows, open the main menu of the system, open the program for spatial positioning at the same time the system will scan the environment in which the user is located, then the user can view the content of the exhibition selection, you can choose the museum introduction module and the cultural relics module, the two modules according to the needs of the use of the choice, after the system will display the relevant information of the holographic images, the user can then interact with the cultural relics The user can interact with the holographic image of cultural relics or exhibition hall information in various ways, including the interaction with the introduction of cultural relics, and after viewing a cultural relic, the user can return to the previous level to select other cultural relics for viewing. If you do not want to continue to view can choose to exit the display system.

3.2.3. Information architecture of the display system. Based on the user's demand information, the cultural relics display system can be divided into 2 functional modules, the museum part and the cultural relics part, the museum part includes the introduction of the museum and the spatial layout of the museum. The museum part includes the introduction of the museum and the spatial layout of the museum. The cultural relics part is mainly: the hologram model of the cultural relics, the basic information of the cultural relics, the background and the meaning of the cultural relics, and the craftsmanship of the cultural relics.

3.3. Visual SLAM-based virtual heritage museum implementation

3.3.1. Three-dimensional reconstruction module. 3D reconstruction is the foundation for building virtual reality environments, and the realism of 3D model reconstruction determines the immersion and user experience of virtual reality. For the reconstruction of general museum exhibits and artifacts, we choose the S-ELAS-based 3D reconstruction method, which includes the steps of acquiring image sequences, feature point detection and matching, camera calibration, acquiring 3D point clouds, mesh reconstruction and texture mapping.

Among these steps, feature point detection and matching, camera calibration, and acquisition of 3D point cloud is the process of restoring the point in the image to the real position of the point, which is equivalent to the conversion from the pixel coordinate system of the image to the world coordinate system.

3.3.2. Virtual Reality Interaction Design. The virtual reality device consists of a helmet, a lighthouse positioning device and a joystick. The relationship and functions between virtual reality devices are shown in Figure 5.

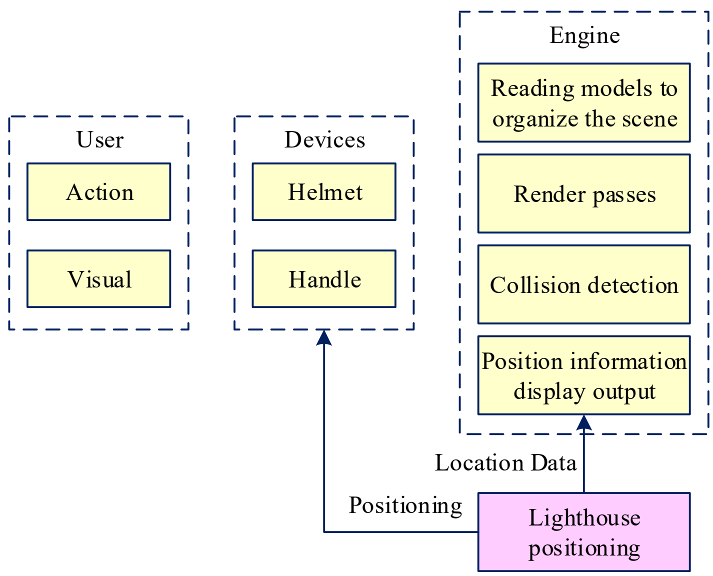

Fig. 5. The relationship and function of virtual reality devices

According to the association and function of each device, various interactive functions can be designed into the cultural museum roaming system, including adding force feedback effect for collision to increase the sense of interactive experience; adding triggering events to display audio and video of cultural relics introduction; and switching the viewpoint through the handle to switch UI options to help children with height limitation or disabled people to visit the museum and other functions.

3.3.3. Distributed Virtual Reality Module. The distributed virtual reality module uses a hierarchical architecture in a clippable tree pattern. Among them, the server is the manager of the clients and the manager of the virtual reality scene. It is responsible for clock synchronization control, system security settings, user rights allocation as well as data transmission, collaborative control and so on.

The main server is the root node of the structure, and the connection between the main server and the backup server, the regional server is an immutable connection, and the connection between the regional server and the clients is a variable connection. The regional servers can be dynamically configured according to the system load, so the whole topology is a clippable tree model as shown in Figure 6.

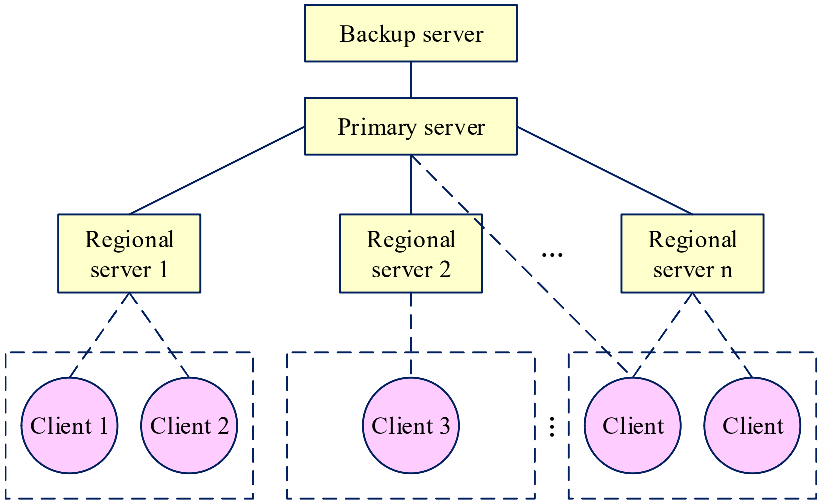

Fig. 6. Clipping tree pattern

4. System measurement and analysis of SLAM-based virtual museums

4.1. Selection of test users for the system

In order to test the performance of the developed virtual museum system and whether it is a good solution to the existing museum system's problems such as less interaction and weak immersion experience, more than twenty users were selected to test the system from various aspects. The basic information of the users is shown in Table 3. The selection principles of users are as follows:
1) Users' naked eye and corrected vision is above 1.0 and no color blindness.
2) Users' colleges and grades are distributed as widely as possible, with the colleges involving the School of Computer Science, the School of Marxism, the School of Education, the School of Psychology, and so on, and the grades covering six grades from sophomore to the third year of master's degree.

The evaluation of the virtual museum system by its users plays a very important role in further improving the design of the virtual museum in the future.

Table 3. User basic statistics

	Stage Ⅰ (N=24)	Stage Ⅱ (N=20)
Age range	18~26	18~26
Mean age	22.55	22.17
Standard deviation	2.28	2.24
Sex ratio(man:female)	13:11	9:11

4.2. Testing process

4.2.1. Stage Ⅰ-Adaptation Training. In order to familiarize the user with the virtual environment, the user was given an adaptation training before proceeding to the formal test. Before entering the formal training, considering the ethical and moral requirements that should be followed in experiments with human subjects, the user was asked to consent to this training after watching a video to understand the use of the VR equipment and the scenes in the VR equipment. During the adaptive training, the user can stop the training for any reason.

4.2.2. Phase II - Experimental Testing. At the end of the adaptive training, the statistics of users willing to participate in the next stage of the test, 20 users said that they were willing to participate in

Stage Ⅱ test, and those who were not willing to participate in Stage Ⅱ test included 4 male students, and the 4 male students were not suitable to participate in the next stage of the test because of the vertigo sensation caused by too much rotation of the head during the operation.

After inviting the 20 test users who were willing to participate in the next stage of testing to the test environment, we firstly introduced the operation process and content of the whole system so that the users could understand the purpose of the test. After the users understood the basic operation process and content, they opened the virtual museum system to experience it, and after completing the operation process of all the tests, they scored MOS for each question in the designed questionnaire.

4.3. Scoring results and analysis

4.3.1. MOS scoring results. After experiencing the virtual museum, users rated the MOS for each question in the designed questionnaire. The partial results of the scoring are shown in Table 4.

Table 4. Part of the score

Numbering	System content presentation evaluation			...	The use of the system is evaluated		
	1	2	3	...	9	10	11
	The scene model is real	Content design is appropriate	Content design is novel and interesting	...	The comfort of the device	Operability of equipment	The expectation of the next use of the system
	1 No	2 Not so good		3 General	4 Good		5Very good
1	5	2	3	...	4	3	3
2	5	3	3	...	5	3	3
3	5	5	3	...	5	3	4
4	5	5	5	...	5	5	5
5	5	5	5	...	3	5	5
6	5	4	5	...	3	5	5
...	...	...	...	...	...	...	...
17	4	3	3	...	3	3	3
18	4	3	3	...	3	3	4
19	4	4	3	...	3	3	3
20	4	4	3	...	3	3	3

4.3.2. Analysis of results. The questionnaire was scored on 11 aspects such as authenticity of the scenario model design, appropriate content volume design, novel and interesting content design, ease of operation of the device, and the degree of expectation for the next use of the system, and the results were analyzed for reliability. The Cronbach's reliability analysis is shown in Table 5.The Cronbach is used to assess the consistency between ratings of the items in the scale, and, in general. The larger the coefficient of Cronbach, the higher the internal consistency between items. If this value is higher than 0.8, it indicates high reliability; if this value is between 0.7 and 0.8, it indicates good reliability; if this value is between 0.6 and 0.7, it indicates acceptable reliability; if this value is less than 0.6, it indicates poor reliability.

As can be seen from the table, the reliability coefficient values of system content presentation evaluation, system function design evaluation, and system usage feeling evaluation are all greater than 0.8, indicating that the data reliability is of high quality and can be used for further analysis.

Table 5. Cronbach reliability analysis

Name		Calibration correlation(CITC)	α coefficient of the a that has been deleted	Cronbach α coefficient
System content presentation evaluation	The scene model is real	0.577	0.835	0.839
	Content design is appropriate	0.734	0.771	
	Content design is novel and interesting	0.772	0.745	
	The content design is accurate	0.685	0.811	
System function design evaluation	The first person called the roaming function	0.695	0.772	0.833
	Instantaneous mobile function	0.676	0.779	
	Peer interaction	0.689	0.773	
	Display control function	0.572	0.822	
System usage evaluation	The comfort of the device	0.855	0.895	0.928
	Operability of equipment	0.855	0.895	
	Expectation of system f use	0.851	0.895	

1) Evaluation and analysis of system content presentation. The content presentation is mainly to evaluate whether the content design of the system is reasonable, whether the scene creation is realistic, and how effective the user's immersion experience is for the system. The histogram of the content presentation evaluation of the system is shown in Fig. 7. S1 scene model design is real, S2 content quality design is appropriate, S3 content is novel and interesting, and S4 content design is accurate.

As can be seen from the figure, regarding the authenticity of the scene model design, the vast majority of people thought it was good or very good. Regarding the design of content capacity, 1 person rated it not so good, 3 rated it average, and 16 rated it good or very good. Regarding the novelty and interest of the content design, 7 people rated it as average, 13 people rated it as good or very good. Regarding the accuracy of the content design, 1 person rated it as average, and 19 people rated it as good or very good. The above shows that the algorithm optimization and material mapping processing used in the model processing in the early stage increased the realism of the system and enhanced the user's immersive experience.

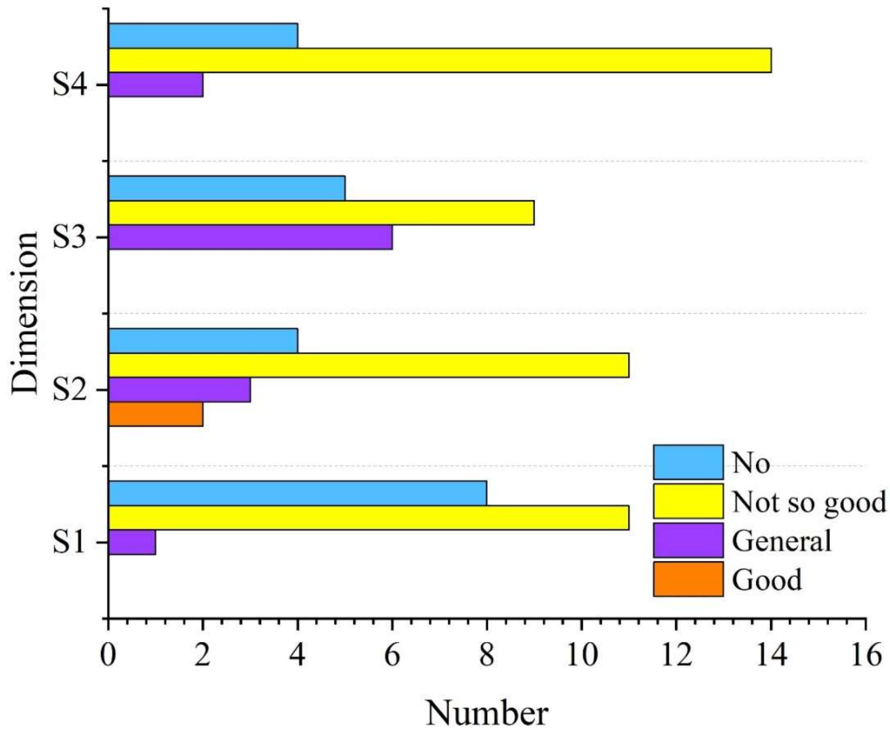

Fig. 7. The content of the system is presented as the column diagram

2) Functional design evaluation analysis. This part is mainly to test the user's evaluation of each HCI function design of the system. The evaluation bar chart of the functional design is shown in Fig. 8. S1 is the first-person roaming function, S2 is the instantaneous movement function, S3 is the gaze interaction function, and S4 is the display control function of the exhibits. From the figure, it can be found that users gave high ratings for all four HCI functions, indicating that the system has good interactivity.

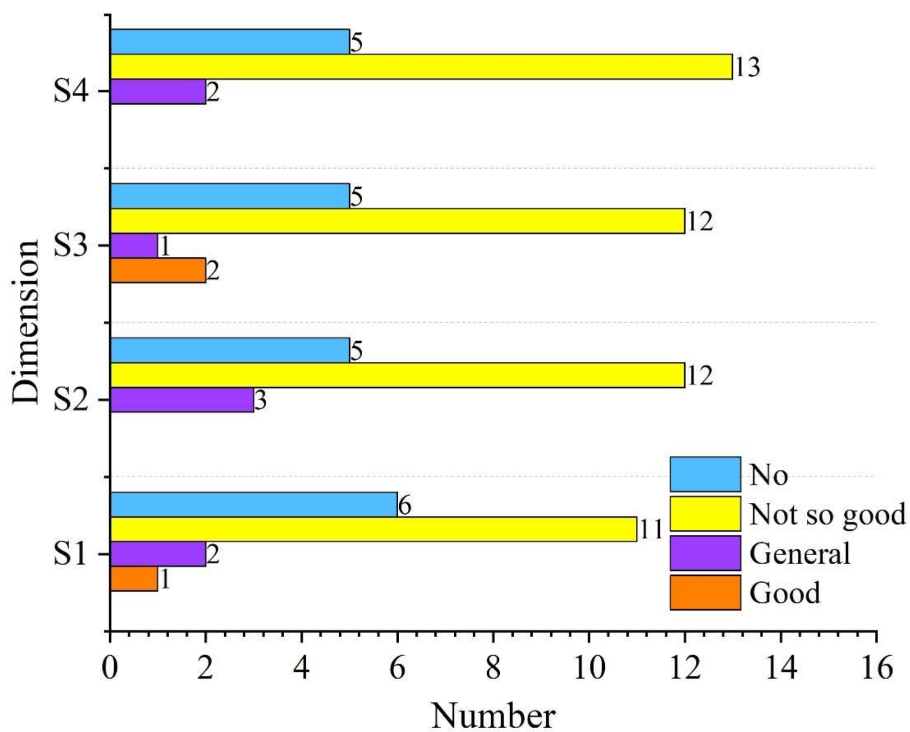

Fig. 8. Functional design evaluation bar diagram

3) Evaluation and analysis of system usage feeling. This section contains three main parts: the comfort of wearing the device, the ease of operation of the device, and the degree of expectation for the next use of the device. The evaluation bar chart of the system usage feeling is shown in Fig. 9. S1 is the comfort of wearing the device, S2 is the ease of operation of the device, and S3 is the degree of expectation for the Nth use of the system.

It can be found that the majority of people rate the comfort and ease of operation of the device as average, which is due to the fact that wearing the device for a long time will make the user feel dizzy, coupled with the unskilled operation of the joystick, resulting in the user not being able to interact well with the museum. The above problems, although they have been noted in the design and acclimatization training, are still unavoidable. However, it can be found that the vast majority of people still have a high level of anticipation for the next use of the system, indicating that the virtual museum system has a good prospect for development.

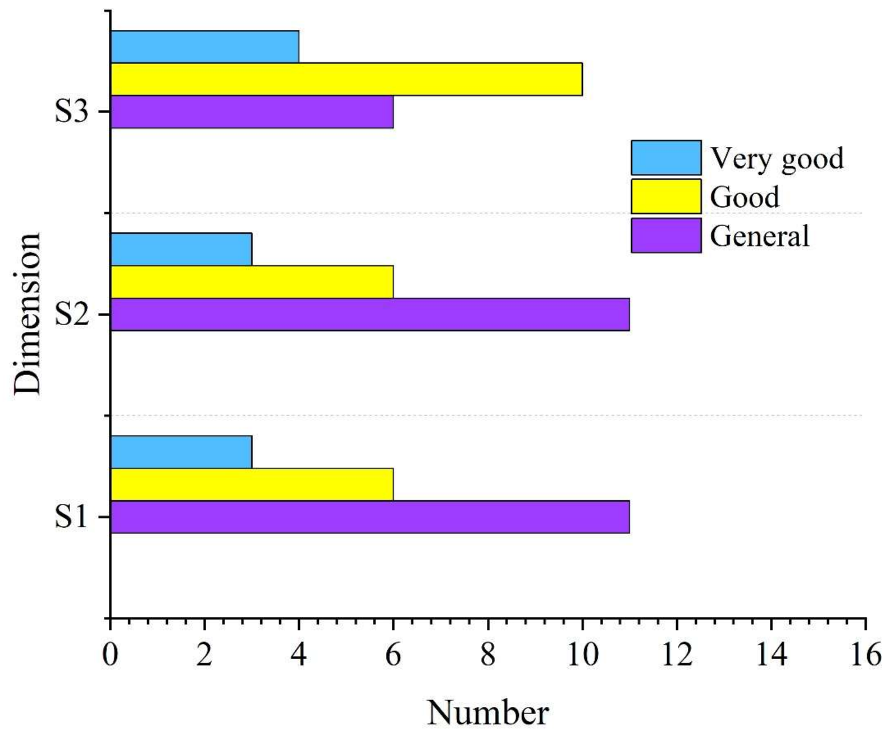

Fig. 9. The evaluation bar diagram of the system's use of feelings

5. Conclusion

The study proposes a binocular stereo matching algorithm (S-ELAS) based on binocular camera as well as 3D point cloud reconstruction and optimization for digital transformation of cultural relic museums. Based on the experimental scene, the original ELAS algorithm and S-ELAS algorithm are used to carry out multi-group comparison experiments for 3D scene reconstruction, and the experimental results show that there are more or less deviations between the reconstructed object representation value and the real value of actual objects in the 3D scene map of S-ELAS, and the mean value of the deviation is -0.046m, and the experimental effect is excellent. And a virtual cultural relics museum based on the combination of visual SLAM system and VR technology is designed, in order to test the performance of the cultural relics museum, users experience the system to test the system, and MOS scoring is carried out after the test. The scoring results show that the system has a better improvement in interactivity and experience compared to the existing museum system.

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