3D Reconstruction Method of Virtual Teaching Laboratory Model Based on Akaze Features

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Abstract. In order to improve the accuracy of 3D modeling of virtual laboratory, a 3D reconstruction method of virtual teaching laboratory model based on AKAZE feature is proposed. In the gradient image, all Gaussian weighted vectors in the region are superposed with the feature points as the center to match the features of the virtual teaching laboratory. Logarithmically increasing according to AKAZE's scale level. The 3D points are searched through breadth-first traversal, and an association graph based on AKAZE features is constructed. Estimate the global rotation matrix, optimal translation matrix and global position information, and obtain all the information of the 3D model library. Through the steps of material acquisition, 3D graphics construction, 3D device construction, virtual object determination and virtual teaching laboratory model release steps, the 3D reconstruction of the model is completed. It can be seen from the experimental results that the maximum matching error between this method and the actual extracted features is 6, which can accurately match the three-dimensional features and achieve the ideal reconstruction effect.

Keywords: AKAZE features · Virtual teaching · Laboratory model · 3D reconstruction

1 Introduction

With the continuous development of virtual reality technology and network communication technology, many colleges and universities have put forward their own virtual laboratory construction plans. In the virtual laboratory, students can either operate on the virtual experimental platform or design their own experiments. Compared with traditional teaching methods, students can understand the learning content more intuitively. 3D simulation model is an important part of virtual laboratory. For students, there are usually three sources for the 3D models in the virtual lab. They are self-developed, downloaded from the Internet, and provided by teachers. The 3D models obtained usually have many problems. For example, the types of models are limited, the format is not uniform, and the adjustment parameters are inconsistent. For this reason, there are also some researches in the field of simulation model resource library at home and abroad.

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Someone proposed a virtual laboratory reconstruction method based on the network 3D model library. This method reduces the coupling between the three-dimensional model and the virtual scene by distinguishing the model library and the database, and storing the model and data separately. The model library is to draw the 3D models repeatedly used in the virtual laboratory with professional modeling tools, and store them into the model library according to the model classification. The database stores the information related to the establishment of the scene according to the specific virtual scene. This completes the three-dimensional reconstruction of the virtual teaching laboratory model [1]. Others have proposed a virtual reality-based virtual laboratory reconstruction method. Using virtual modeling tools to achieve realistic 3D scenes, users can roam in the virtual scene. Learning resources are obtained by interacting with the 3D model in the scene through the keyboard and mouse [2]. However, most researches mainly focus on the management of the model itself, without considering the data information generated by the interaction between the 3D model and the scene. For a virtual scene with interactive functions. In addition to the description information of the model itself, it should also include the parameter information of the model in the scene, as well as the data entered by the user. Moreover, in the process of 3D reconstruction of the model, the accuracy of feature matching needs to be improved. Therefore, a 3D reconstruction method of virtual teaching laboratory model based on AKAZE features is proposed. Centered on the feature point on the gradient image, all Gaussian-weighted vectors in the region are superimposed to match the features of the virtual teaching laboratory. According to the scale level of AKAZE, it increases logarithmically, and searches for three-dimensional points through breadth-first traversal, thereby constructing an association graph based on AKAZE features. The three-dimensional reconstruction of the model is completed through the steps of material acquisition, three-dimensional graphics construction and virtual teaching laboratory model release.

2 Feature Matching of Virtual Teaching Laboratory Based on AKAZE Features

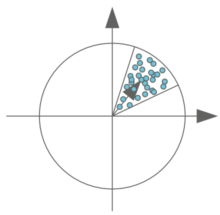
Virtual laboratory is an open networked virtual experiment teaching system based on VR virtual reality technology. It is the digitization and virtualization of various existing teaching laboratories [3]. The Virtual Lab is designed to create a real virtual environment. This environment not only has realistic experimental scenes, experimental instruments, and experimental equipment, but also the virtual experimental equipment constructed must be able to achieve a fine-grained three-dimensional display that is operable and observable, so as to truly restore the experimental process. AKAZE (Accelerated KAZE) feature extraction algorithm is a local feature descriptor algorithm, which can be regarded as an improvement of the SIFT algorithm. It uses nonlinear diffusion filtering iterations to extract and construct the scale space, and uses a method similar to SIFT to find feature points. In the descriptor generation stage, a similar method of ORB is used to generate descriptors, but the descriptor has more rotation invariance features than ORB.

The construction of the existing virtual reality system is slow and the delay is large. A laboratory often includes buildings, buildings, ceilings, floor tiles, water and electricity, instruments, equipment, operating desks, blackboards, lecterns, chairs, cabinets and many other elements. And its elements influence each other. To complete an experiment, it is necessary to comprehensively use each element, its attributes, and functions to achieve a good experimental teaching effect.

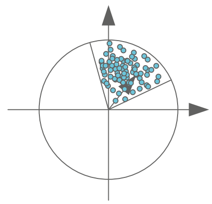
After determining the virtual teaching laboratory model, AKAZE can use the Hessian matrix to detect local extreme points. The Hessia matrix of a point in a two-dimensional image describes the gray gradient changes in the neighborhood of the point in all directions:

$$R_i = \lambda^2 \left(R_{xxi} R_{yyi} - R_{xyi} R_{xyi} \right) \tag{1}$$

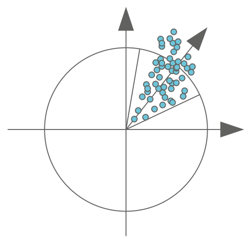
In formula (1), λ is the normalized scale factor in the corresponding image group. The maximum value is obtained by comparing each pixel processed by the Hessian matrix with its 8 neighboring pixels of the same scale and the pixels in the 3 × 3 window on



(a) The first-order differential R_x and R_y are in the same quadrant



(b) First order differential R_x and R_y in different quadrants



(c) The first-order differentials R_x and R_y are not exactly in quadrants

Fig. 1. AKAZE computes eigenvalue directions

two adjacent scales. The pixel point where the maximum value is located is the feature point. If the two points are in the adjacent layer and the distance is within the scale range, the duplicate point is considered to be deleted [4].

The main direction of the feature point is determined before the feature description. On the gradient image, with the feature point as the center and the radius λ as the statistical range, the Gaussian weighting operation is performed on the first-order differential R_x and R_y of the neighborhood of the feature point. Then take a 60° fan-shaped window to traverse the entire circular area around the feature point, and superimpose all Gaussian weighted vectors in the area. The direction represented by the fan-shaped area with the highest superposition value is the main direction of the eigenvalue, as shown in Fig. 1.

It can be seen from Fig. 1 that the feature point neighborhood is divided into several grids such as 3 × 3 or 4 × 4. And rotate in the main direction. Discrete points are obtained by resampling at intervals of scale λ in each grid. Calculate the average gray value of discrete points and the first-order gradient information in the horizontal and vertical directions. The descriptor information of 3-bit dimension is generated, which can make the descriptor have rotation invariance and distinguishability [5].

3 3D Reconstruction of Virtual Teaching Laboratory Model Based on AKAZE Features

3.1 Association Graph Construction Based on AKAZE Features

After feature matching on the image sequence, the spatial relationship of objects in different images is usually related to the sequence of the image sequence. Therefore, it is necessary to establish the neighbor relationship between images: if there are a large number of matching pairs between the two images, it means that there is an adjacent spatial relationship between the two images. In a multi-view image sequence, each image has adjacent pictures. The relationship between common feature points in an image sequence can be described by establishing a trajectory track. For example, suppose that a point in the space corresponds to the feature point in the three images $f_1 f_2 f_3$. The feature f_1 in the first image matches the feature f_2 in the second image. The f_2's in the second image match the features in the third image. These features can then be concatenated to form a set $\{f_1, f_2, f_3\}$[6]. A track vector is formed by combining the number of the image and the number of the feature points. A track describes a common feature point in an image sequence and also corresponds to a point in 3D space [7].

According to the scale level of AKAZE, it increases logarithmically, there are n groups, and each group contains m layers. The layers in each group use the same scale as the original image. Based on this, the resulting scale values are:

$$\alpha_i(n, m) = \alpha_0 2^{n+m/m} \tag{2}$$

In formula (2), α_0 represents the initial value of the scale. The nonlinear diffusion filter model is in units of time. Hence the need for a scale parameter in pixels [8].

For an input image, after Gaussian filtering, the gradient histogram of the image can be calculated to construct the conduction matrix W_i. The step size ι is obtained from a set of evolutionary time differences. All images in nonlinear scale space can be obtained through the AOS algorithm, and the scale space of image A is expressed as:

$$W_{i+1} = (H + \tau W_i)W_i \tag{3}$$

In formula (3), H represents an identity matrix. τ represents the step size.

Search for a track of 3D points by breadth-first traversal. First sort the feature points of all image sequences. Then, for each feature point, it is searched by means of breadth-first traversal to find out whether the neighbor image of the image has its corresponding feature point. If found, it is considered that the feature point belongs to a track. Then new neighbors are added to the queue, and the neighbor image search continues until all images are found [9].

3.2 Image Model Building

The virtual teaching laboratory model based on AKAZE features consists of three parts: model library and database, scene management system, and visual management, as shown in Fig. 2.

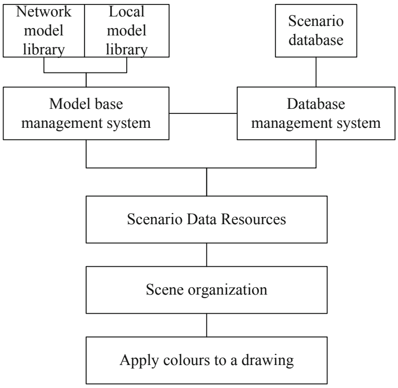


Fig. 2. A virtual teaching laboratory model based on AKAZE features

3D Model Library

Global location information exists in the 3D model library. Extracting information related to feature matching from this information requires accurate estimation. The detailed steps are:

Step 1: Global Rotation Matrix Estimation

In the undirected association graph obtained by the improved method, there are three-view constraints between images, which are better than two-view constraints. The global matrix can be estimated from the relative rotation matrix between the images in the correlation graph.

In the correlation graph, an image I_i, I_j is provided. The relationship between its relative rotation matrix E_{ij} and their global rotation matrix E_i, E_j is:

$$E_{ij} = E_{ij}E_j \tag{4}$$

where, the relative rotation matrix is obtained by decomposing the eigenmatrix obtained by matching pairs.

Assuming that there are n pairs of matching images in the image set, there should be n − 1 relative rotation matrices, which are substituted into the above equation. The estimated value of the global rotation vector can be obtained by the least squares method, and the estimated value should satisfy the orthogonality [10].

Step 2: Optimal translation matrix estimation

To solve the global translation matrix, the local translation matrix under three views should be obtained first. The solution method of the local translation matrix under three views is described as follows [11]. First, the translation vector of the camera in the three-view local coordinate system is calculated. Then calculate the reprojection error of the matching points, and delete the points with too large errors. Finally, the optimal translation matrix in the local coordinate system is obtained.

For three-view $\left(I_i, I_j, I_k\right)$ in a three-view set. Their respective rotation matrices are $\left(E_i, E_j, E_k\right)$. The set of spatial points corresponding to the three-view matching points is O. There is a point O_1 in O, and the corresponding pixel point in image I_i is $\left(g_i, g_j\right)$. Calculate the reprojection error for this point.

Step 3: Global location information estimation

Through the above steps, the relative rotation and translation $\left(E_{ij}, T_{ij}\right)$ of each image in the image set I are obtained. Then the global position information of all image feature points can be obtained. Ideally, the relationship between the spatial position of the image I_i, I_j and their relative pose transformation is as follows:

$$Q_j - W_{ij}Q_i = \varepsilon_{ij}T_{ij} \tag{5}$$

In formula (5), ε_{ij} represents a scale factor. Q represents global location information.

The above equation is an equation under ideal conditions, but in fact it cannot be completely eliminated because of the noise data. As well as the physical errors generated by the camera process, the above formula cannot be strictly established. The actual situation is as follows: There is a point A in the space at the global position. Its pixel positions in the two photos are point B and point C, respectively. These three points should represent the same point, but in fact there is a certain deviation. The optimal solution of the scale factor can be considered to minimize the Euclidean distance between point B and point C relative to point A.

Scene Management System

The scene management system includes two parts: the model library management system and the database management system. The model management system is independent of the specific application field. A software system that classifies and maintains models and supports model generation, storage, query, execution, and analysis applications. Experts and users in various fields can use the model library management system to find the 3D models they need. Put into the virtual scene, the database management system realizes the storage and reading of the virtual scene data.

The model base management system and the database management system jointly manage the objects in the virtual scene. When the user selects an existing virtual scene, the database management system first accesses the scene database. Take out each piece of data, get the index information, position parameters, and interactive data of the 3D model in the model library. Pass the index number to the model repository management system to find the model. Restore the model to a specific location in the scene based on parameter information. When the user clicks on the model, the interactive information of the model is displayed. When the scene is reproduced, the model library management system provides two ways to call the model. One is to directly call the 3D model in the network model library to the virtual scene. The other is to download the models in the network model library to the local model library in advance and then call them.

Visual Management

Virtual reality takes full advantage of scientific visualization techniques. Use virtual modeling tools to achieve realistic 3D scenes. Users can roam in the virtual scene, interact with the 3D model in the scene through the keyboard and mouse, and obtain learning resources.

The visual management part is mainly responsible for establishing virtual scenes, importing 3D models, realizing scene roaming, and managing interactive operations. The rendering of the scene is realized by virtual reality technology.

3.3 Calculation of Global Rotation Matrix and Translation Matrix

After using the RANSAL algorithm to filter out the wrong two-view matching relationship, it is necessary to select a reliable two-view rotation matrix as a parameter, and based on this, the global rotation matrix can be solved. First, the maximum spanning tree is used to calculate the initial global rotation matrix. Then calculate the distance between the multiplication of the rotation matrix in a ring and the identity matrix to judge whether the relationship between the two views is correct. After the two-view relationship is obtained, the global rotation matrix can be solved based on this. To solve the global translation matrix, the local translation matrix under three views should be obtained first. The solution method of the local translation matrix under three views is as follows. First, the translation vector of the camera in the three-view local coordinate system is calculated. Then calculate the ghosting error of the matching points, and delete the points with too large errors. Finally, the optimal translation matrix in the local coordinate system is obtained.

3.4 Rebuild Process Design

According to the scale and characteristics of the virtual laboratory, as well as the tools and conditions of the developers, the system in this paper mainly uses field photography to collect data. 3DMax is used as the 3D modeling tool, and Photoshop is used for texture processing of the material collected from the field. Import the model into Unity as a development engine, and import the model into the engine to add components to add interactive features. Finally, use the test and release system. There may occasionally be an issue in VR environments opening 3D models whose textures are not correctly mapped to the underlying model mesh. Poorly effective texture mapping can produce noticeable distortions in the appearance of the model's surface, such as unwanted seams, stretched or squeezed areas in the texture pattern. It is therefore necessary to use Photoshop to select the reparameterization option, edit and create the optimal surface coverage model.

Material Collection
The materials collected by the virtual laboratory materials mainly include the topography and elevation data of the entire main building and the campus, electronic photos of the main building, sidewalks, squares, pools, greening, other facilities, and experimental equipment. Take pictures on the spot and use photoshop for image optimization. The main thing is to crop and denoise the image first. And use the magic pen to cut out the parts that need to be textured to meet the needs of model building.

3D Graphics Construction
Use 3DMax to construct the graphic image to form the terrain near the main building. Plan and satellite maps for the main building. First, make topographic contours to provide height information for topography. Use ArcMap to generate virtual layer elevation grades, marked with different levels of grayscale. Create a new drawing plane in 3DMax, and make the x and y directions according to the degree of detail. In the UVN map editor, add a picture taken in the field.

3D Device Construction
Laboratory devices and instruments are mainly photographed and combined with advanced modeling tools, and the color and texture of the oscilloscope are photographed. Shapes and effects are obtained using the advanced modeling tools Mesh, Patch and NURBS available in 3DMax. Different lines have different thicknesses and need to be rendered in layers to get the best realistic effect. Complete the construction and synthesis of small objects such as oscilloscopes, power supplies, spectrum analyzers, and resistors. In the implementation process, the camera view can be combined with the 3D view for modeling, which can reduce the complexity of modeling as much as possible.

Virtual Object Determination
Combined with AKAZE features, the 3D model created by 3Dmax is imported into the 3D engine, making it a virtual object that can be called and processed. Then add dynamic components and custom components to add interactivity to virtual objects. Complete human-computer interaction, element interaction and visual interaction between various virtual objects. To build a virtual laboratory system.

Virtual Teaching Lab Model Released
After the processing of AKAZE features, the virtual laboratory can run in the 3D engine. As shown in Fig. 3.

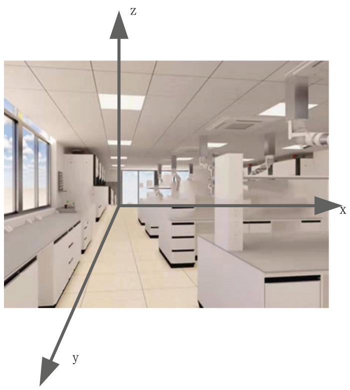


Fig. 3. 3D model of virtual teaching laboratory

As can be seen from Fig. 3, in order to improve the applicability and compatibility of the system, the virtual laboratory needs to be transformed into an executable file, which can be applied to each user's system. Therefore, combined with the publishing function of AKAZE, a virtual laboratory platform that can be used by multiple platforms can be realized.

4 Simulation

The test of the 3D reconstruction method of virtual teaching laboratory model based on AKAZE features proposed in this paper is an important link in the development of virtual laboratory. Only through complete system testing can the final effect of virtual laboratory development be verified. Ensure that the developed platform can fully realize the design goals and meet the needs of users.

4.1 Simulation Process

The functional tests of the virtual laboratory mainly include basic functional tests (such as student login test, administrator login test, teacher login test) and main functional tests (scene roaming test, experimental teaching test, experimental operation test, online question answering test). Through the tests of these three aspects, the function of the virtual laboratory is explicitly output, and it is tested whether the actual operation of the virtual laboratory meets the functional design and user needs. The specific test flow chart is shown in Fig. 4.

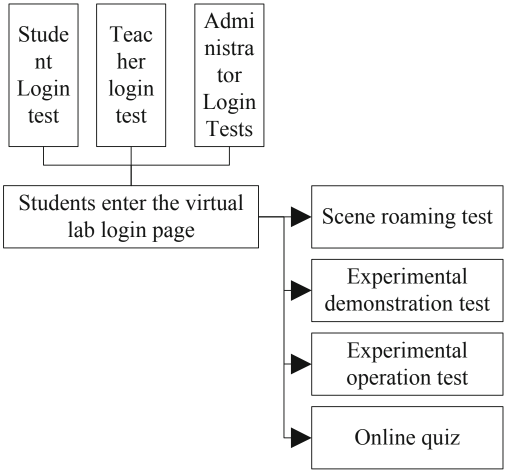


Fig. 4. Virtual laboratory simulation process

4.2 Feature Matching Result Analysis

The virtual laboratory reconstruction method based on network 3D model library (Reference [1]), the virtual laboratory reconstruction method based on virtual reality (Reference [2]), the learning signed distance 3d object reconstruction from static images (Reference [3]) and the 3D reconstruction method of virtual teaching laboratory model based on AKAZE feature are used respectively. The feature matching results are compared and analyzed, as shown in Table 1.

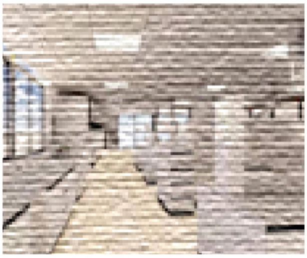
Table 1. Comparison of feature matching results of three methods

Actual extraction quantity/piece	Network 3D model library	Virtual reality	Learning signed distance methods in static images	AKAZE features
10951	10098	9892	10021	10951
20290	19982	19082	19652	20290
23452	22983	23009	22086	23452
23435	22203	23123	22725	23435
36754	35784	34278	34029	36760

It can be seen from Table 1 that the virtual laboratory reconstruction method based on the network 3D model library, the virtual laboratory reconstruction method based on virtual reality and the signed distance learning method in static images cannot completely match the features, and the maximum matching errors are 1232, respectively. 2476 and 2725. However, using the 3D reconstruction method of the virtual teaching laboratory model based on AKAZE features, the maximum matching error is 6.

4.3 Analysis of Reconstruction Renderings

The virtual laboratory reconstruction method based on network 3D model library, the virtual laboratory reconstruction method based on virtual reality and the 3D reconstruction method of virtual teaching laboratory model based on AKAZE feature are used respectively. The reconstruction effect diagram of the virtual teaching laboratory model is compared and analyzed, as shown in Fig. 5.



(a) Reconstruction method of virtual laboratory based on network 3D model library

(b) Reconstruction method of virtual laboratory based on virtual reality

(c) Learning signed distance methods in static images

(d) 3D reconstruction method based on AKAZE features

Fig. 5. Three methods of virtual teaching laboratory model reconstruction renderings

It can be seen from Fig. 5 that the reconstruction method of virtual laboratory based on the network 3D model library, the reconstruction method of virtual laboratory based on virtual reality and learning the symbolic distance in static images have wrong matching features, resulting in poor reconstruction effect. The 3D reconstruction method of the virtual teaching laboratory model based on AKAZE features can accurately match the 3D features, so that the reconstruction results can achieve ideal results.

5 Conclusion

The proposed 3D reconstruction method of virtual teaching laboratory model based on AKAZE features. The AKAZE algorithm is used to detect and extract the features of the image sequence, and the RANSAC algorithm is used to further optimize the matching results and save the coordinate information of the correct matching pairs. Then build an undirected correlation graph and obtain a global rotation and translation matrix, thus completing the three-dimensional reconstruction of the virtual teaching laboratory model. For example, using CUDA parallelization to speed up the point cloud construction process. Using this model in experimental teaching can effectively exercise students' logical analysis ability and practical ability.

Carry out research based on 3D reconstruction and carry out a large number of experimental verifications, obtain target scene pictures through digital cameras, and go through a series of processes. Compared to incremental 3D reconstruction, a more satisfactory reconstructed model is obtained, but there is still a lot of room for improvement. For problems that can be improved and researched, it boils down to the following points:

(1) The 3D reconstruction is a dense point cloud, and the model is not realistic enough. In the follow-up, we can also study the implementation methods of point cloud registration, meshing, texture mapping and other steps.
(2) Compared with the incremental reconstruction method, the speed of the method in this paper is greatly improved. In addition to algorithm optimization, hardware acceleration can also be considered.
(3) In the 3D model reconstructed by this method, the dense point cloud will contain points other than the target. These points are generated successfully but are not needed. At present, these clutter points can only be removed manually, and it is one of the directions worth researching to make the machine automatically identify and remove these points.

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