

Research and Realization of VR&AR Fusion Technology in Coal Mine Power Supply Simulation System

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Abstract

Coal mine power supply simulation experiment is a fusion of relay protection technology, mine electrical engineering, power system analysis and other multidisciplinary engineering applications of the experiment, and has a wide range of applications in the training of coal mine employees and related courses in mining colleges and universities, this paper aims to provide a virtual simulation system for teaching and training, so as to improve the efficiency of the experiment. The system is based on virtual reality and augmented reality technology, adopts Unity 3D as the development engine, introduces the collision detection algorithm of hybrid enveloping box, which effectively improves the processing efficiency of detection, and realizes the accuracy enhancement of the recognition map by integrating the ACE+CLAHE algorithm in the development of augmented reality function.

Keywords

Coal Mine Power Supply; Virtual Reality; Augmented Reality; Collision Detection; ACE+CLAHE Algorithm.

1. Introduction

In 2021, China's coal production is 4.13 billion tons, an increase of 5.7% over the previous year. 2022, China's total coal production is 4.45 billion tons, an increase of 8% year-on-year. Although the total installed capacity of new energy power generation in the year-on-year increase, but China still has more than 50% of the coal used in the field of power generation, in general, coal as energy security production "ballast" identity in the short term can not be replaced. When it comes to coal, it is inextricably linked to safety. After the continuous introduction of relevant national policies, the effect of coal safety production is quite obvious in recent years, but coal mine accidents still occur from time to time. In 2022 alone, there were 367 accidents and 518 deaths, which is still a huge number. In view of the above problems, it is necessary to design a set of experimental simulation system with interactive experience, which can be used to improve the experimental level and engineering design ability of students and employees in related majors[1].

In order to improve the course quality of coal mine power supply teaching experiments, this study mainly adopts virtual reality technology and is supplemented by augmented reality technology, combines the two with coal mine power supply experimental teaching, comprehensively applies the Unity 3D platform, Blender, 3Ds Max, Visual Studio 2019 and other software, and adopts three-dimensional modeling technology, database processing technology, C# scripting Programming

technology, image processing technology, gesture recognition and other technologies, research and design a set of VR/AR-based coal mine power supply teaching simulation system[2].

2. Requirement Analysis of System

Before the development of the system, the focus of the simulation platform must be the use of the population research, according to the shortcomings of traditional teaching, research and judgment of the system requirements and personnel preferences, and the expected function of the comparison, in order to improve the shortcomings, in order to provide the basis for the construction of the platform architecture.

2.1 Requirements Screening based on the KANO Model

For the main problems in traditional experiments, a systematic pre-selection of demand analysis is needed, and demand screening is not only decided by a simple slap of an individual, which requires a scientific method of statistical analysis. In 1984, Prof. Noriaki Kano of Japan proposed a theoretical model for prioritizing the screening of users' degree of demand, which is able to represent the non-linear relationship between product functions and user satisfaction, and further analyze the degree of influence on users after realizing the corresponding demand, referred to as the KANO model. It can represent the non-linear relationship between product features and user satisfaction, and further analyze the degree of impact on users after realizing the corresponding demand, referred to as KANO model.

The KANO model is categorized into five attributes as follows:

- (1) Necessary requirements, which are obviously functions or features that must be present, or understood as minimum requirements. It is regarded by users as an attribute that the system should have, and when this type of requirement is met, satisfaction may not increase, but if the requirement is not met, the user's satisfaction will be greatly reduced. For example, a system needs to guarantee operational integrity first and foremost, and if experiments do not run smoothly, then satisfaction is bound to drop.
- (2) Expectation-type demand, growth-type demand, is a demand that can reflect competitiveness. User satisfaction is directly related to the degree of fulfillment of this need, and increasing the degree of fulfillment of this type of need is extremely beneficial to increasing user satisfaction. For example, experiments are fresh enough that users can be very engaged, but users are not as sensitive to this type of need as they are to essential needs.
- (3) Charming requirements, i.e., functions or features that exceed the user's expectations and serve as a kind of icing on the cake. Charming attributes are similar to the colorful eggs in movies or games, if you don't provide this demand, user satisfaction will not be reduced, if you provide this demand, user satisfaction will be greatly improved. For example, there is good collision feedback in scene roaming.
- (4) Non-differentiated requirements, which users do not care about and have no role in improving the user experience. Whether this requirement is provided or not, user satisfaction does not produce a change, and for this topic, this requirement can be left out to avoid bloating the software. For example, the system's introduction of a large number of circuit diagrams, where students can find similar content in books, will not offer any advantage when placed in simulation.
- (5) Reverse requirements, i.e., additive requirements, may also be some operational errors. When the system provides the function or when such running error occurs, the user's satisfaction will decrease and even cause strong dissatisfaction. For example, system flashback, frequent secondary prompts for experimental operations, which wastes time, will make users impatient.

For each attribute of the above KANO model, the relationship can be depicted as shown in Figure 1. The horizontal axis indicates the degree of functionality availability, while the vertical axis shows the level of user satisfaction. As in a regular planar coordinate system, the closer to the positive direction, the higher the level of functionality and user satisfaction.

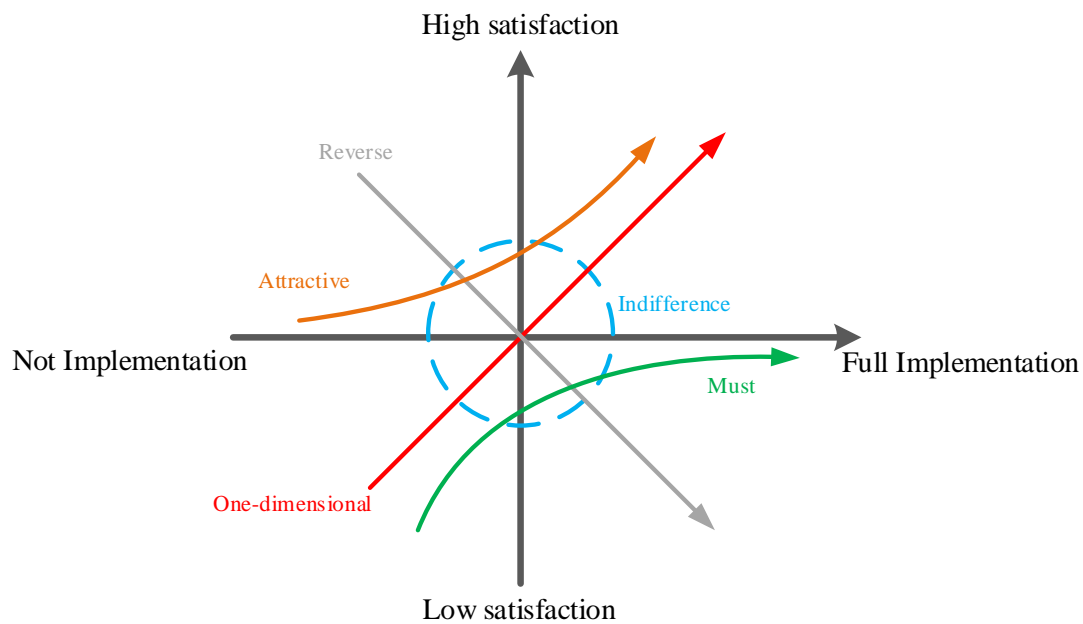


Figure 1. KANO model diagram

2.2 System Function Confirmation

The analysis method of KANO model is mainly to screen the standardized questionnaires with credibility after receiving the questionnaires, and to categorize the attributes of various needs from the results in the form of asking questions by whether or not to provide a certain function, and the classification criteria are shown in Table 1.

Table 1. KANO model questionnaire form

A user's attitude		This function is not available				
		Like	Only natural	Not matter	Reluctantly	dislike
Have the function	Like	Q	A	A	A	O
	Only natural	R	I	I	I	M
	Not matter	R	I	I	I	M
	Reluctantly	R	I	I	I	M
	dislike	R	R	R	R	Q

The user's final demand for a certain function is determined by the Better-Worse coefficients, and the Better and Worse coefficients are calculated as shown in Eqs. (1) and (2).

$$Better = (A + O) / (A + O + M + I) \tag{1}$$

$$Worse = -1 \times (O + M) / (A + O + M + I) \tag{2}$$

Where, Better - coefficient of satisfaction when a certain function is available; Worse - coefficient of dissatisfaction when a certain function is available.

A - Attractive attribute frequency; O - Desired attribute frequency;

M - Frequency of required attributes; I - Frequency of undifferentiated attributes;

Q - stands for questionable results, which may be misunderstood by the user and do not have to be calculated.

Through the above calculations, the Better-Worse coefficient graph is plotted with the Better coefficient as the horizontal coordinate and the Worse coefficient as the vertical coordinate, as shown in Figure 2.

where the larger the coefficient in the vertical coordinate, the higher the satisfaction, and the larger the absolute value of the coefficient in the horizontal coordinate, the higher the degree of dissatisfaction.

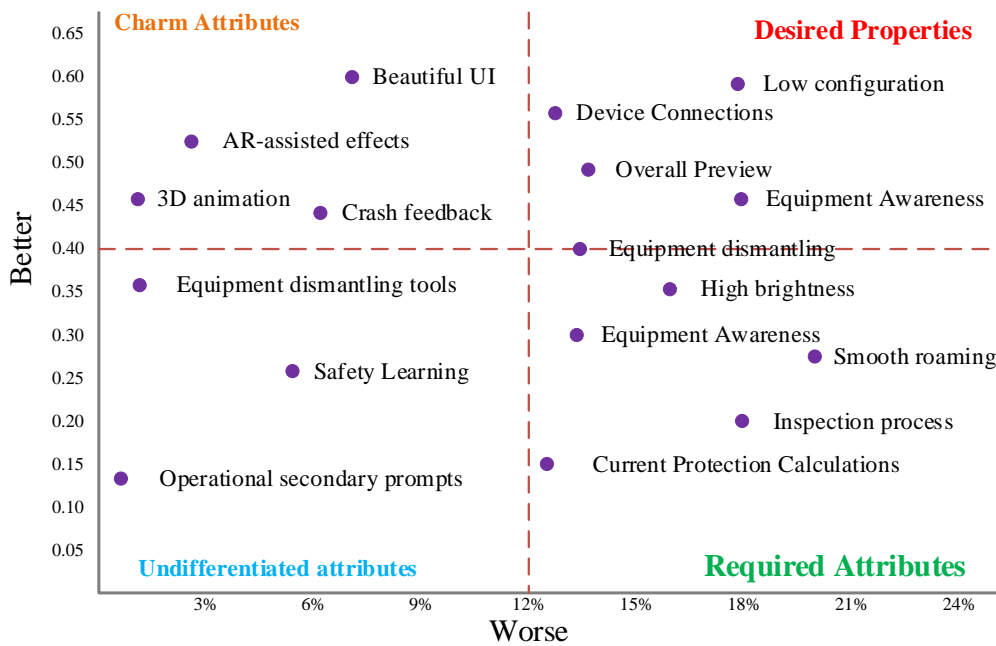


Figure 2. Better-Worse coefficient plot

In Figure 2, in the first and fourth quadrants, i.e., the desired attributes and the required attributes are the key elements in the design of this system, the charismatic attributes in the second quadrant are the best possible functions, and in order to improve the system fluency and to reduce the unnecessary workload, the functions contained in the undifferentiated attributes in the fourth quadrant should be discarded. The pre-formulated functions of the system after statistical analysis are shown in Table 2.

Table 2. Summary of system prefabrication functions

Design focus function		Maximize the function	Unnecessary
Device cognition	Low hardware	Beautiful UI	Secondary cue
Maintenance	device attachment	3D animation	Safe learning
Current protection	Full Preview	Collision Detection	Disassembly tool
Dismantling	Navigation	Expandability	Internal diagram
highlight	Well-modelled	AR auxiliary effect	Online
Roaming smooth			Model dimensioning

3. Virtual Reality Function Realization

The development of virtual reality features is an important part of the system. In the process of 3D scene production, the system is divided into four scenes to realize their functions respectively, combined with C# programming to complete human-computer interaction, connection of each scene,

saving of database, etc., and based on the mixed level of the enclosing box algorithm to improve the efficiency of collision detection of objects.

3.1 Overall Development Framework

Unity connects multiple scenes during system development. Typically, each scenario only carries out a portion of the system's functionality. In order to cover all the functions of the system, multiple scenarios must be designed and integrated, and the overall goal of system development can be achieved by calling them in an orderly manner. Scenarios are invoked in different order according to the functions they are responsible for, and the system will invoke each scenario one by one in an orderly manner through a specific process.

In accordance with the overall system architecture of this study, the user is first required to authenticate the login interface by entering relevant personal information. Once the account information is successfully verified, the user can access the main operating interface of the system or choose to log out at this moment. The main function of the main operation interface is to organize and activate different sub-scenarios, from which the user can choose to enter the sub-scenarios of a specific module. Within any of the sub-scenarios, the logout operation takes the user back to the main interface, where the user has the option of continuing to navigate through the other sub-scenarios or logging out of the system altogether. This operation flow can improve the development and management efficiency of the system, and the main operation flow is shown in Figure 3.

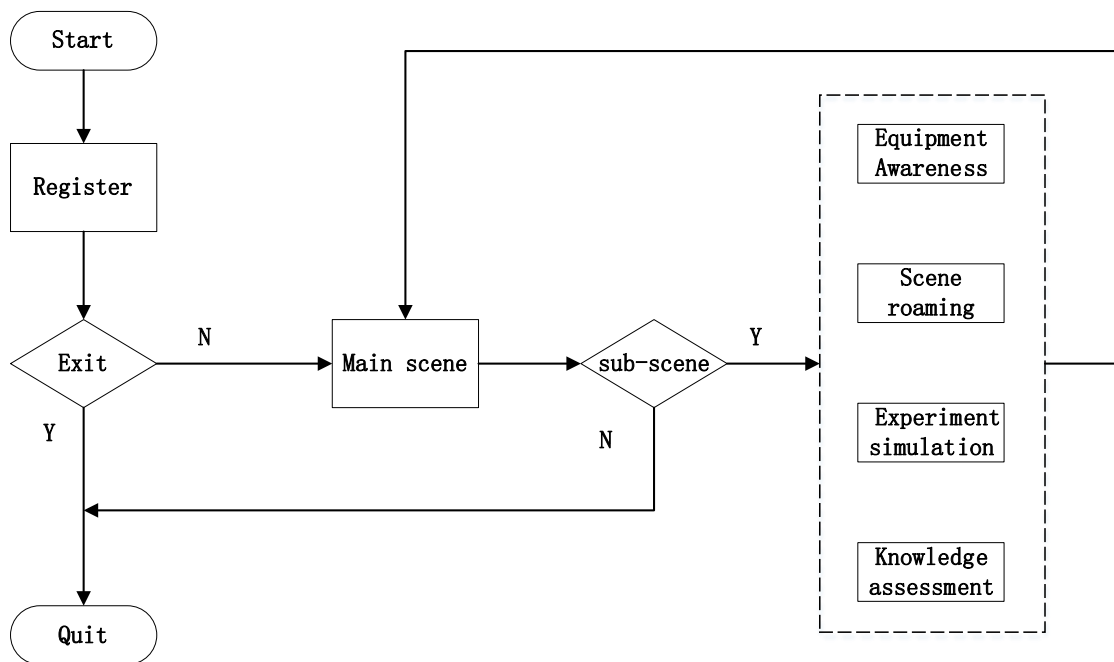


Figure 3. System operation flow chart

3.2 Key Technology Research

During the development of the system, it is natural to encounter some problems, such as animation effects, how to reduce the memory footprint, the collision process of the objects, etc.

3.2.1 Lod Technique

LOD (Level Of Detail) technique, also known as hierarchical detail modeling technique, is a real-time processing technique for three-dimensional computer graphics, which is designed to reduce the real-time utilization of system hardware and thus increase the rate of operation.

A virtual scene includes hundreds or even thousands of 3D models, each of which includes at least points, lines, surfaces and textures, and the more detailed the model will take up more system resources. If each model is rendered during system operation, it will cause a great burden to the

computer operation, which will lead to frame dropping, lagging, and even crashing of the system. According to the design expectation, when the camera is close to the model, we want to be able to see the details of the model, and in the process of distance being pulled away, the model is gradually blurred, this principle needs to use LOD technology[3].

The LOD technique generates different layers of models based on the starting model as a sample to accommodate the different requirements of model complexity and differences in the details of visual observation, which need to be described and drawn in different details in various regions of the model, and the accuracy of the model increases accordingly when the camera gets closer to the object.

As shown in Fig. 4, so that LOD 0 represents the initial fine model, LOD 1 represents the intermediate model, then LOD 2 represents the coarse model, and the model accuracy gradually decreases when the viewpoint moves from LOD 0 to LOD 2.

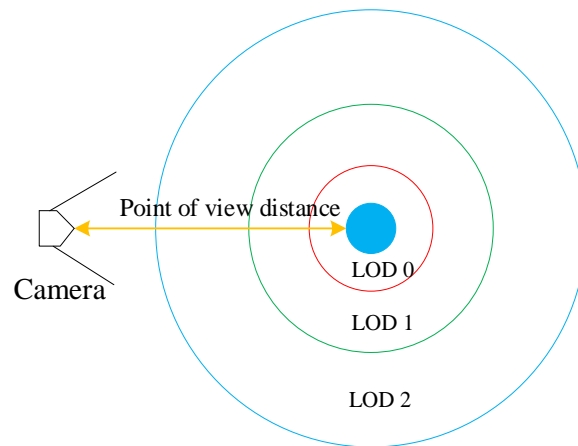


Figure 4. Plot of model accuracy versus viewpoint

3.2.2 Bounding box detection algorithm

Collision detection technology is an important part of the virtual scene to realize the system to monitor the motion behavior and judge the interaction between the user and the device. In the real world, physics defines that the collision between objects must change the motion state of the object (static or motion), which shows that the core of its detection is to define the contact area of the collision. To realize the collision detection technology, the principle is to use regular colliders to approximate the shape and structure of complex objects, and to determine whether the objects collide by detecting the intersection of the boundaries[4].

(1) AABB bounding volume tree

One of the more widely used current enveloping boxes, which spreads 3D into a 2D planar format, has an algorithmic principle shown in Figure 5.

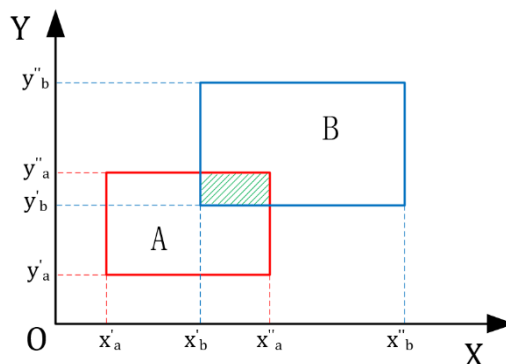


Figure 5. AABB bounding box schematic

As shown in Figure 5, the green shaded portion between the two enclosing boxes is the collision region, which is promoted from the two-dimensional plane to the three-dimensional space by analyzing the projection of the enclosing boxes in the Z-axis, and the constraints for the occurrence of the collision are shown in Eq. (3).

$$\left\{ \begin{array}{l} (x'_a \leq x'_b \ \& \ \& x'_b \leq x''_a) \ || \ (x'_b \leq x''_a \ \& \ \& x'_a \leq x''_b) \\ (y'_a \leq y'_b \ \& \ \& y'_b \leq y''_a) \ || \ (y'_b \leq y''_a \ \& \ \& y'_a \leq y''_b) \\ (z'_a \leq z'_b \ \& \ \& z'_b \leq z''_a) \ || \ (z'_b \leq z''_a \ \& \ \& z'_a \leq z''_b) \end{array} \right. \quad (3)$$

(2) OBB bounding volume tree

This system focuses on VR and AR as an auxiliary technology, both of which use the OBB enclosing box. The algorithm is defined by calculating the covariance matrix to determine the boundaries and directions of the enveloping box, and then the separation axis theorem is used to detect whether two objects intersect.

1) An object usually consists of multiple regular or irregular faces. Firstly, the vertices of each face should be determined, and then a correlation matrix is constructed based on these vertices, which can be used to represent the correlation and common characteristics between these points, and these correlation matrices are actually covariance matrices. The covariance calculation formula is shown in equation (4).

$$\text{cov}(X, Y) = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{n - 1} \quad (4)$$

Where X, Y is the two variables for calculating the covariance and n represents the full number of variables. When the relationship of $\text{cov}(X, Y) = \text{cov}(Y, X)$ is satisfied, the matrix form of the covariance can be obtained, as shown in equation (5).

$$C = \begin{pmatrix} \text{cov}(x, x) & \text{cov}(x, y) & \text{cov}(x, z) \\ \text{cov}(y, x) & \text{cov}(y, y) & \text{cov}(y, z) \\ \text{cov}(z, x) & \text{cov}(z, y) & \text{cov}(z, z) \end{pmatrix} \quad (5)$$

By diagonalizing the covariance matrix, the eigenvalues and eigenvectors are obtained, and the coordinate axes of the OBB are the eigenvectors, and further the center of the enclosing box coordinates can be determined.

2) The separation axis theorem is often used for intersection detection of OBB enclosing boxes. Intuitively, in two-dimensional space, if a line can be found so that the two enclosing boxes are located on both sides of the line, then the two boxes do not intersect, this line is regarded as a segmentation line, and in three-dimensional is a segmentation plane, the detection principle is shown in Figure 6.

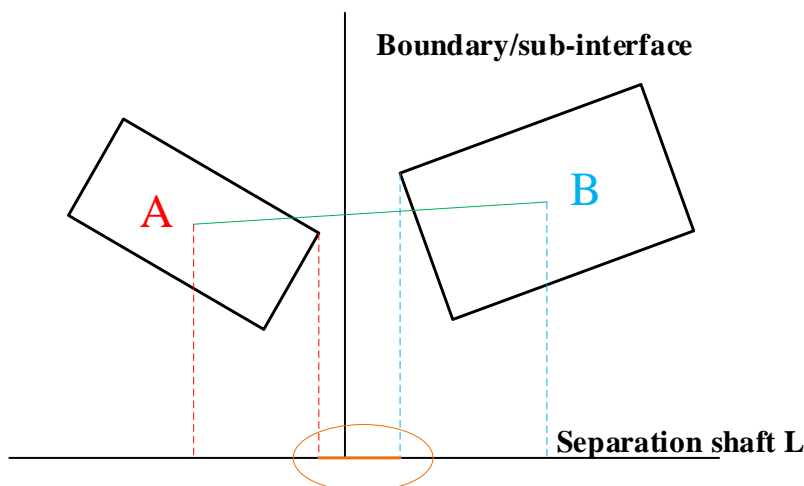


Figure 6. Separation axis detection schematic

Where the straight line L is the separation axis, project the enclosing boxes A and B onto L, find the point with the closest distance between them, and determine whether they overlap.

The system utilizes the above two envelope box detection algorithms in combination, which can reduce the time complexity to logarithmic level and effectively reduce the number of tests.

3.3 Scene Roaming Implementation

Realize scene roaming through collision detection and 3D interaction. Various devices are mainly checked in the scene roaming. In normal learning, it is difficult for students to operate the field equipment, but in the scene roaming they can get different experimental effects through realistic equipment models and interactive experiences[5]. The ground substation is shown in Figure 7, and the working face distribution point is shown in Figure 8.

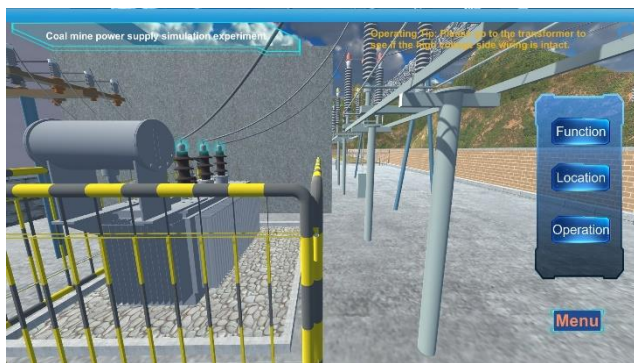


Figure 7. Ground substation

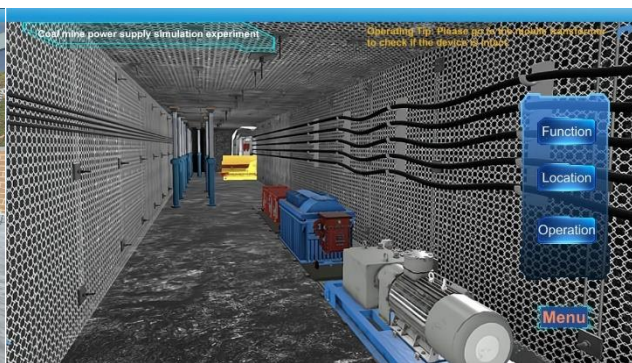


Figure 8. Power distribution point

4. Augmented Reality Feature Development

In order to enrich the learning mode and enhance the user's understanding of the internal structure of electrical equipment, the system is supplemented with augmented reality technology for disassembly and installation experiments of the equipment.

4.1 Three-dimensional Registration Technique

3D registration technology is the key to mobile AR applications, as well as the basis for measuring the performance of the system. Its main principle is to superimpose virtual information onto the real target object, to recognize the attitude of the camera relative to the real world in real time, and to determine the exact position of the virtual information to be superimposed on the projection surface. Augmented reality spatial coordinates can be divided into model coordinate system, world coordinate

system, camera coordinate system, imaging coordinate system, the process of its realization of tracking registration is the process of coordinate transformation, that is, ultimately in the corresponding position in the imaging plane to determine the virtual model and synchronized display, augmented reality in the coordinate transformation relationship shown in Figure 9. Most of the current technology to realize three-dimensional registration through computer vision-based, hardware sensor-based, hybrid registration of three ways.

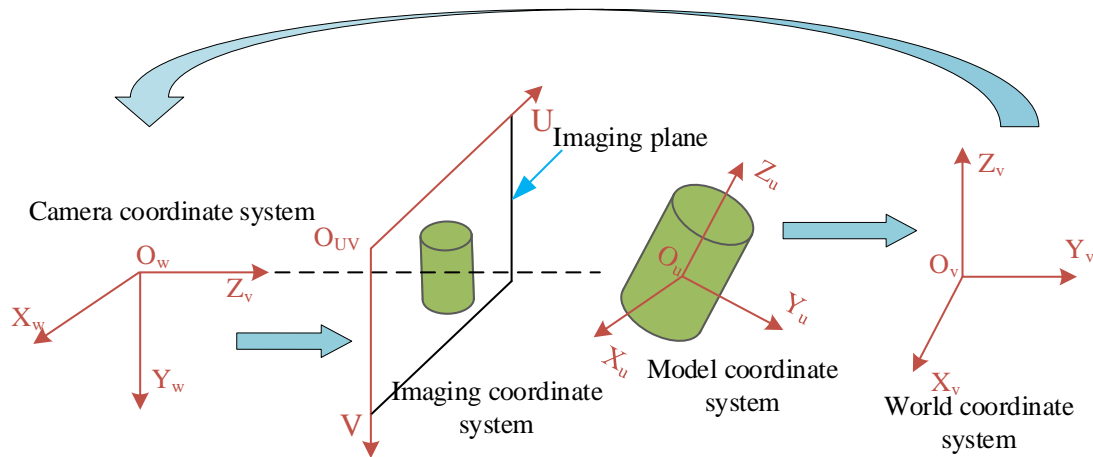


Figure 9. Schematic diagram of coordinate transformation relationship

If there is a point $p(x_u, y_u, z_u)$ in the local coordinate system $O_u-X_uY_uZ_u$ of the model and its coordinate in the corresponding world coordinate system $O_v-X_vY_vZ_v$ is xyz , the relationship between the two is shown in equation (6).

$$[x_v \quad y_v \quad z_v \quad 1]^T = B \begin{bmatrix} x_u \\ y_u \\ z_u \\ 1 \end{bmatrix} = \begin{bmatrix} R_1 & t_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_u \\ y_u \\ z_u \\ 1 \end{bmatrix} \quad (6)$$

where B is the transformation matrix and the rotation R_1 is a 3rd order orthogonal unit array representing the translation vector of the transformation matrix. The process of transforming the coordinate $p(x_v, y_v, z_v)$ in the world coordinate system $O_v-X_vY_vZ_v$ to the camera coordinate system $O_w-X_wY_wZ_w$ is shown in equation (7).

$$[x_w \quad y_w \quad z_w \quad 1]^T = T \begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} = \begin{bmatrix} R_2 & t_2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} \quad (7)$$

where, T is the external parameter matrix of the camera, R_2 and t_2 are still the rotation and translation quantities.

The transformation of a point $p(x_w, y_w, z_w)$ in the camera coordinate system $O_w-X_wY_wZ_w$ into the imaging coordinate system $O_{uv}-UV$ is shown in equation (8).

$$k \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} a_x & 0 & u_0 & 0 \\ 0 & a_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (8)$$

where k is the scale factor and ax, ay, u0, y0 are internal parameters of the camera, which can be determined by the calibration method.

Considering the lens deviation of the actual camera and introducing the correction factor λ, the process of transforming the world coordinate system Ov-XvYvZv to the imaging coordinate system Ouv—UV can be written as shown in equation (9).

$$k \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} a_x & \lambda & u_0 & 0 \\ 0 & a_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} [R \ t] \begin{bmatrix} x_v \\ y_v \\ z_v \\ 1 \end{bmatrix} \quad (9)$$

Eventually, a representation of the local coordinate system Ou-XuYuZu of the model can be introduced to transform to the imaging coordinate system Ouv—UV as shown in Equation (10).

$$k \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} a_x & \lambda & u_0 & 0 \\ 0 & a_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} [R \ t] \begin{bmatrix} x_u \\ y_u \\ z_u \\ 1 \end{bmatrix} \quad (10)$$

4.2 Vuforia based Target Recognition

Vuforia is a plug-in developed by Qualcomm to realize the augmented reality function, which is very convenient to use in combination with Unity. Users can upload the corresponding information to the database, and utilize the computer vision technology to detect and track the markers on the markers to realize a variety of virtual simulation functions, and the configuration process of Vuforia can be divided into three parts[6].

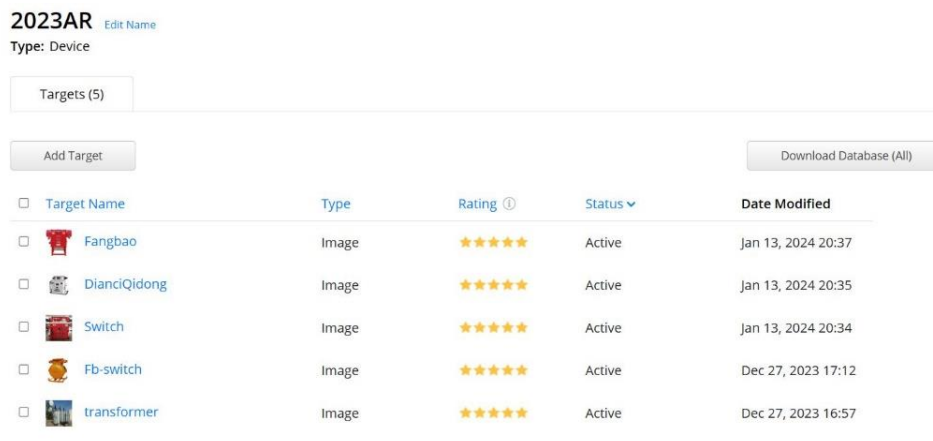


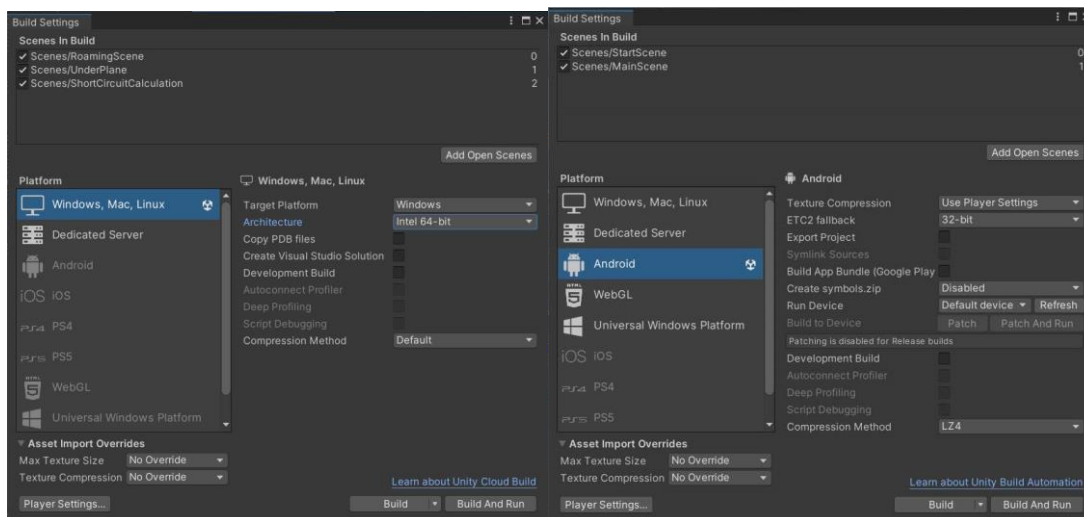
Figure 10. Vuforia Recognition Effect

- (1) Database creation. First of all, you need to register and login in the official website of Vuforia, and then get the key to facilitate the follow-up work, and then add the database (Datebase), name the database created, and finally complete the creation.
- (2) Creation of the gallery. The annotated pictures uploaded in the database need to meet the format requirements and be under 2M. After uploading, you can view the details of the recognition rate of the pictures, and their recognition accuracy is determined by the star rating, and the recognition effect is displayed as shown in Figure 10, and should be re-uploaded when the accuracy is lower, i.e., two stars and below, so as not to affect the recognition effect.
- (3) Unity configuration. Get the Vuforia SDK, download the resource package and import it into Unity 3D for relevant settings, add the Image Target component, import the virtual model in FBX format, and finally complete the settings of relevant parameters in the settings panel.

4.3 Simulation Function Implementation

Unity allows applications to be published on multiple platforms, and the simulation system mainly serves university teachers and students. The export setting interface is shown in Figure 11(a).

The experimental platform export of the augmented reality simulation function is similar to the above process, the AR system developed in Unity can also choose a variety of export platforms, and this experimental simulation mainly focuses on the Android terminal. The export interface is shown in Figure 11(b).



(a)PC

(b)AR

Figure 11. System Release Settings

Table 3. AR interface UI introduction

Button	Function
autorotation	After clicking, the model will rotate automatically, and the rotation speed will be controlled by the script. Click again to stop the automatic rotation and turn to gesture control
introduce	The basic introduction of the device, including the use, features, etc
One-click disassembly	Click and completely disassemble the model
restoration	Reset the model that is disassembled or disassembled step by step to restore the model to its original appearance
Progressive disassembly	Click the button to disassemble one part at a time

Click the AR button to enter the system, the UI in the system contains six Button buttons, one of which is the Exit button, and the functions of the remaining five are shown in Table 3.

By aligning the operating device to the identification diagram, the corresponding identifier appears and the one-button disassembly of the transformer model is shown in Figure 12.

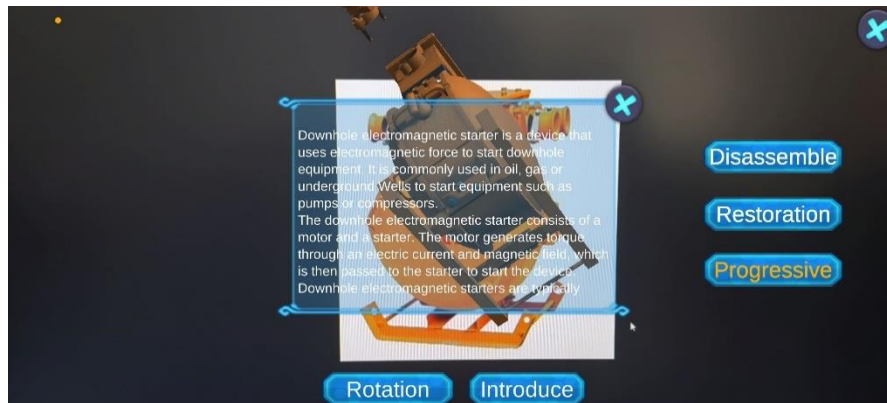


Figure 12. Step-by-step disassembly and equipment introduction

5. Conclusion

This paper designs and develops the coal mine power supply teaching experiment simulation system, compared with the traditional experimental teaching, the system has the advantages of low cost, clear interface, strong interactivity, easy operation, high security, basically accomplished the expected goal, and can effectively improve the learning and training efficiency of the relevant personnel.

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