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Design of Electrical System Teaching Platform Based on PLC and Implementation of Virtual Simulation Training System

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Abstract. Electrical automation technology is one of the essential skills that electrical students must master. This article focuses on building virtual simulation scenarios for practical electrical courses. Firstly, based on the current shortage of practical training equipment, insufficient expansion and updating capabilities of practical training equipment, and the explosive demand for virtual simulation training platforms in universities, a survey and analysis were conducted on the actual needs of electrical system courses, and the framework of the electrical teaching platform was built with a demand-oriented approach. Virtual simulation training is a functional link in the teaching platform. Then, based on specific training projects, the process of building virtual simulation experimental scenes was introduced, and models and data processing schemes between models were completed; Finally, based on the constructed course platform, the course tasks were completed in real classrooms and positive feedback was received.

Keywords: simulation, simulation, 3d modeling

1 Introduction

Virtual simulation, also known as simulation technology, is a technique that simulates real systems in a virtual environment. Virtual simulation maps information from the real environment to a computer. By constructing a real system model in a virtual environment, conducting experimental analysis on the model, and leveraging the powerful data processing capabilities of computers, the same experimental results as the real system can be obtained. Therefore, virtual simulation technology has become an emerging technology in various fields [1].

Experimental teaching is an important part of modern curriculum teaching. It is not only a continuation of theoretical teaching in the classroom, helping students digest and absorb learned knowledge, but also can stimulate students' thinking about the knowledge they have learned, and apply the methods and experiences they have mastered in the experimental process to practice. Experimental teaching is an important link between knowledge and ability, theory and practice transformation. Due to the diverse functions, numerous components, and complex operating states of real electrical systems, traditional electrical system course experiments are completed on specific practical teaching platforms, and these platforms are mostly built on physical objects. The experimental platforms used in teaching mainly include electrical control system experimental equipment for electrical system analysis, control experimental platforms including relays and PLCs for control circuits, and electrical programmable training platforms including PLCs. These training platforms can basically meet the requirements of demonstrating experimental principles and reproducing experimental phenomena. However, these devices are customized for experiments, and expensive prices are one aspect. More importantly, they are different from the actual equipment encountered by students in their actual work positions. Generally, the technology and equipment used in such teaching platforms are far behind actual production [2].

In addition, in terms of feedback on practical training results, due to the enclosed nature of the training equipment and safety considerations, students can only observe experimental results through information such as relay actions, indicator lights turning on and off, and alarm signal flashing. It is impossible to observe the waveform changes of various electrical quantities such as voltage, current, etc. during the training process, nor can they observe the working process of the experimental equipment. Students' intuitive awareness is not high, which is not conducive to their understanding and thinking of electrical principles knowledge.

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At the same time, due to the strong targeted functionality of training equipment, the cost of adding training equipment functions is high, and it is even impossible to add functions. Therefore, it is difficult to flexibly expand in existing electrical training equipment. In actual practical training courses, for colleges and universities that focus on skill training, each student needs to be able to operate training equipment independently to complete training tasks. Therefore, there should be sufficient training equipment in teaching, which is a challenge for financially constrained universities. From the perspective of talent cultivation programs, traditional electrical system teaching, although an integrated course of theory and operation, still mainly focuses on cognitive and confirmatory practical training, lacking experimental content designed independently for electrical systems, and lacking in exploration. The experimental content is relatively outdated, and emerging technologies in electrical systems are difficult to appear in the arrangement of experimental teaching [3].

Therefore, the work done in this article to address the above situation is as follows: Firstly, based on the current shortage of training equipment and the explosive demand for virtual simulation training platforms in universities, an analysis of the virtual simulation requirements for electrical systems and the construction of an overall virtual simulation experimental system framework were conducted; Then, based on specific training projects, the process of building virtual simulation experiment scenes was introduced, and the models and data processing schemes between models were completed; Finally, based on the constructed course platform, the course tasks were completed in real classrooms and positive feedback was received.

2 Related Work

Many scholars in China have conducted relevant research on electrical system teaching and the design of virtual simulation scenarios for electrical systems, and have achieved rich research results. Guodong Cheng from China University of Mining and Technology has designed an electrical control training platform based on S7-1200 PLC to address issues such as outdated PLC training equipment technology, poor intuitiveness, and difficulties for students to design independently. Analyzed the working principle of the training platform and provided reference training projects, and introduced how to use the training platform to achieve closed-loop speed control of asynchronous motors. This training platform has improved students' practical abilities and achieved good teaching results [4].

Lixin Yu from Nanjing University of Information Engineering and Technology elaborated on the characteristics of the Electrical Control and PLC Application course, the problems and improvement methods in the experimental teaching of the course, and explored the innovation of experimental content and teaching methods, including problem oriented teaching, project driven teaching, application of virtual experimental platforms, teaching feedback and evaluation [5].

Qihan Liu from Fujian Water Resources and Electric Power Vocational and Technical College believes that electrical control and PLC technology are important technologies in the field of engineering, and the choice of their teaching mode directly affects students' learning effectiveness and the cultivation of innovation ability. The article introduces the teaching mode of electrical control and PLC technology based on virtual simulation technology, providing reference and inspiration for improving the quality of electrical control and PLC technology teaching [6].

Minchai Hao from the Communication University of China analyzed the course of sensors and detection technology using virtual simulation technology, explored practical training projects that are difficult to implement in current courses, introduced real enterprise cases, used virtual simulation technology to complete high cost and difficult to implement practical training projects, developed practical training projects that combine virtual and real, and used practical training projects to solve teaching problems such as thermocouple sensors and capacitive sensors that are high cost and difficult to implement in courses. During the practical training process, a virtual simulation environment was used for information collection, and the construction of circuits was used to control equipment, guiding students to establish logical and engineering thinking and enhance their practical abilities [7].

Based on the EETbasic elevator simulation experimental platform, Hui Li designed a control program for a single 6-story elevator PLC control system using Siemens' Boruto V18 and S7-PLCSIM Advanced V5.0 software. He applied it to teaching practice and completed the setup of virtual simulation software, configuration settings for Boruto software, and communication settings between software based on the structure of the elevator system, the characteristics of EETbasic software, and the control principles of the elevator control system. He also developed a modular and structured programming method for a single elevator control program based on the FB block. Finally, the teaching situation and effectiveness of the virtual simulation experiment platform applied for 4 years were introduced [8].

Junlei Ma has completed virtual simulation and communication simulation of KUKA robots for a PLC control platform that includes industrial robots. In order to improve students' learning efficiency and skill level in industrial robot maintenance, an intelligent training and assessment system based on KUKA industrial robots has been designed. The system can set up control circuit faults and restore faults on the upper computer according to requirements, solving the heavy workload of manual setting of faults and restoration wiring for teachers during training and assessment. Practice has proven that this system can effectively improve the efficiency of practical training and assessment of industrial robots for students, and reduce the workload of teachers [9].

Cong Zhang from Hangzhou University of Electronic Science and Technology proposed a design scheme for an industrial control 3D configuration virtual simulation experimental platform based on WebGL. The platform uses WebGL technology to build a realistic 3D industrial simulation environment, and combines PhysiJs technology and NodeJs technology to achieve real-time rendering and data communication of model motion. This simulation platform includes functions such as scene loading, model assembly, motion control, PLC communication configuration, and experimental effect simulation. It can quickly build virtual simulation experimental teaching scenes for PLC software development in typical industrial environments. By virtually reproducing real scenes, the problems of limited experimental sites, expensive equipment, and applicability to multiple experimental scenarios can be effectively solved, thereby improving the quality of talent cultivation in the field of industrial control [10].

In order to achieve the work on virtual simulation in this article, the composition structure of this article is as follows: Chapter 2 introduces the research results of relevant scholars, Chapter 3 completes the construction of a practical training platform based on the needs of practical teaching, Chapter 4 completes the construction of a practical training model and data processing for a specific common practical training, and Chapter 5 completes the use of the practical training platform designed in this article in a real teaching environment. Chapter 6 is the conclusion section, which summarizes the achievements and shortcomings of this article.

3 Design of Electrical System Teaching Platform

This section mainly completes the design of the electrical system teaching platform. Starting from the requirements, the platform design first analyzes the practical training and teaching needs of electrical related majors. Then, the overall framework of the PLC based electrical system teaching platform is built, and the refinement of the virtual simulation function in the platform is completed.

3.1 Analysis of Teaching Platform Requirements

In the era of rapid development of the Internet, there are some problems in offline practical teaching of traditional electrical engineering technology specialty, which need to be solved urgently. Although universities have made efforts and attempts in hands-on practice by building experimental training rooms, purchasing training equipment, and even designing specialized practical courses for students, they still cannot meet the fragmented and personalized learning needs of students, and cannot meet the teaching needs of the integration of theory and practice in electrical engineering majors. The current practical teaching of electrical engineering mainly faces the following two problems: firstly, the high cost of purchasing, managing, and maintaining laboratory resources. Some practical teaching activities require specialized experimental training venues and hardware equipment, while the construction of offline experimental training rooms requires significant cost investment; Secondly, with the continuous emergence of new technologies and applications in the field of electrical engineering, practical training teaching content also needs to constantly follow the trend of technological development and adapt to technological iterations, such as introducing training equipment and scenarios that match new PLC, automated production lines, and other courses. This requires teaching resources to be flexibly and quickly updated and deployed. At present, the equipment resources in the experimental training room are being updated slowly, and are also constrained by funding, making it impossible to keep up with the development pace of electrical technology applications and the current development needs of teaching. Some experimental courses, such as "Application of Electrical Technology", "Integration of Intelligent Manufacturing Systems", and "Operation and Maintenance of Intelligent Production Lines", require physical equipment for testing. Considering that some experimental scenarios require large automated production lines, the relevant theoretical experimental projects cannot be fully realized, resulting in a significant reduction in the experimental effect of the courses and the inability or difficulty in achieving the expected teaching effect [11].

Therefore, this article first analyzes the actual needs of electrical teaching, constructs an electrical system teaching platform, stores digital teaching resources in the cloud, so that students and teachers can use them anytime and anywhere, and utilizes the advantages and characteristics of cloud computing technology to achieve efficient integration and sharing of resources, improve resource utilization, and reduce investment in education costs; In response to the limitations of time and location in offline teaching environments, by uploading rich online learning resources, students can learn theoretical knowledge online anytime and anywhere; In response to the low utilization rate of offline teaching resources and teachers' neglect of students' hands-on teaching, the platform provides virtual simulation software, exercise assignments, and other resources related to offline practice activities, allowing students to access these resources online and gain an understanding of the purpose, content, principles, and other aspects of offline experiments in advance; The online practice environment provided by virtual simulation software and other resources can allow students to independently practice the installation of experimental equipment, experimental operation steps, and other practical activities online in advance. Through the online exercise homework function, students can internalize the corresponding knowledge, and have a deeper understanding, digestion, and absorption of the problems and phenomena that arise during the experimental process. This is conducive to improving the current situation of students having only half knowledge of experimental operation steps in offline practice, and can also clearly reflect their mastery of practical courses. The usage requirements of the platform can be roughly divided into two categories: student users and teacher users.

In addition, from the perspective of student users, the main functional requirements of the platform are reflected in the ability of the teaching platform to provide digital learning resources for online viewing of various practical courses and the ability to conduct online practical activities. The digital resources include rich learning resources such as videos, animations, PPT presentations, pictures, etc. of various experimental activities, which enable students to use them more conveniently, freely and flexibly control their learning time and progress, and reduce teaching costs; In response to the questions that students may have during the learning process, the platform needs to provide interactive features for online discussions between students and teachers, ensuring that students can communicate and interact with teachers or other students in a timely manner [12]. Therefore, the summary of students' needs on the entire learning platform is shown in Fig. 1.

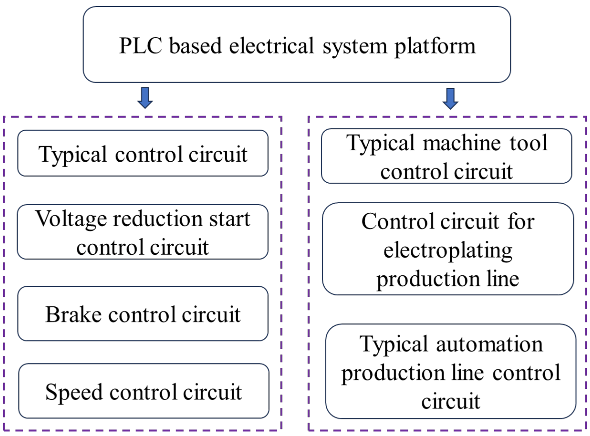

Fig. 1. Content framework diagram of electrical experimental system

3.2 Overall Framework Design of the Platform

The overall architecture of the electrical system based on PLC is divided into front-end presentation layer, business logic layer, data access layer, and platform support layer, which are interrelated and independent of each other [13].

1) The front-end presentation layer, which is the display part of the page, is mainly developed using the Vue.js3.0 framework. Its function is to provide a web user interaction interface and provide corresponding functional

permissions based on the user's identity authentication during login. It receives and responds to data requests from student users and teacher users based on the user's identity.

2) The business logic layer is the core of the entire platform, mainly using the web framework Django based on Python programming language to control the business logic of various functions of users and teachers. Using modular thinking, the platform's functional modules are divided into user modules, course modules, interactive modules, and practical modules. The modules are independent of each other and have low coupling, which is conducive to improving the processing efficiency of platform data.

3) The data access layer uses the most popular relational database MySQL [14] as the platform data storage container

4) In terms of cloud platform support, the open source project OpenStack framework is used for building, which simply means installing the required OpenStack components on existing infrastructure. It can greatly simplify the process of building the cloud platform and has good scalability, providing IaaS services (Infrastructure as a Service) for the entire practical teaching platform. IaaS uses virtualization technology to form a unified virtual resource pool for efficient automated management of all available hardware devices. The structure of the electrical system teaching platform is shown in Fig. 2.

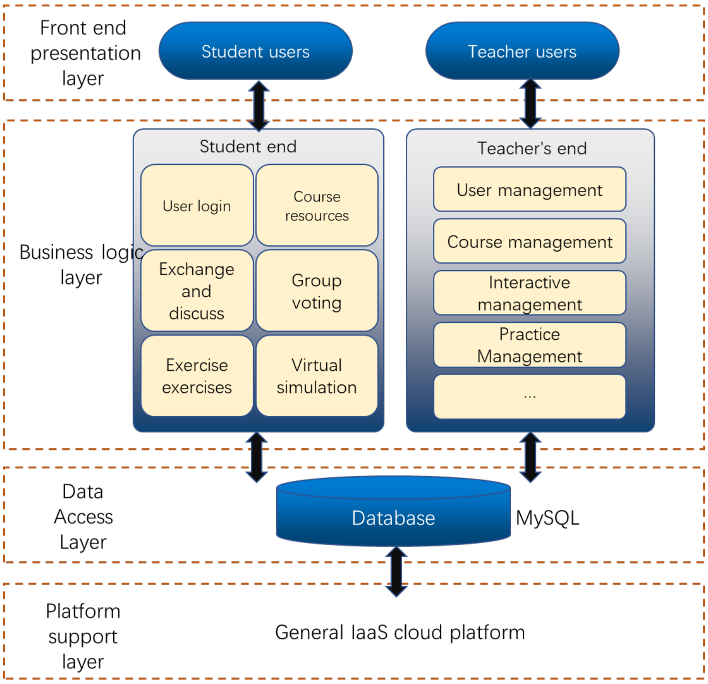

Fig. 2. Overall framework of simulation training teaching platform

3.3 Implementation of Virtual Simulation Process

The main function of the virtual simulation library is to allow students to select corresponding projects on the virtual simulation library page, and teachers to set corresponding tasks for practical exercises based on the key and difficult points in the course knowledge points. Through the carefully designed practical activities of the virtual simulation software as a carrier, students and users can apply the pre learned theoretical knowledge to the practical operation process, so that students can better digest and absorb the knowledge. In addition, for some training projects that are difficult to carry out and limited by the number of training equipment, the virtual simulation library function allows students to download and open relevant virtual simulation software uploaded by teachers on the teaching platform for simulation training, providing a vivid and realistic online practical learning environment for students to preview and practice the installation, debugging, and operation of controllers and electrical equipment involved in experimental courses in advance [15].

The use of simulation training platforms can not only enhance students' interest in learning, but also save the cost of purchasing real components, assist students in deepening their understanding of the practical operation process of experimental training courses, and improve students' learning effectiveness. The page of the virtual simulation library function displays information about virtual simulation software projects in the form of charts, including project names, project introductions, responsible persons, etc. Student end users mainly provide viewing and downloading permissions. After clicking and selecting different virtual simulation projects, they will enter the corresponding project details page, which will display the description, usage instructions, and provide a download and installation window of the virtual simulation software. After downloading the software resources, they can click to start and access the virtual simulation software, and then complete the corresponding practical operations according to the task requirements assigned by the teacher. The flowchart of the virtual simulation process is shown in Fig. 3.

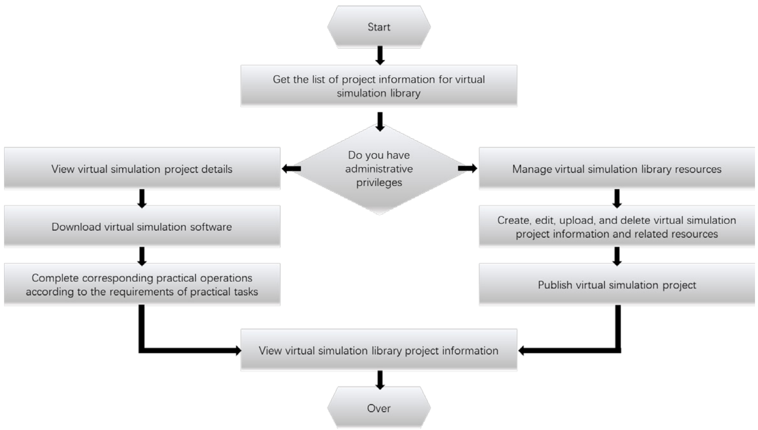

Fig. 3. Flow chart of virtual simulation training process

After the above process, the analysis of the requirements for the teaching platform and the construction of the platform have been completed. The next chapter will focus on building a PLC based electrical equipment training system for virtual simulation functions.

4 Implementation of Virtual Simulation Training System

In the process of constructing electrical models for electrical systems, commonly used 3D modeling software include CATIA, UG, SolidWorks, etc. In the process of building a 3D model in this article, SolidWorks software is mainly used for modeling based on the friendliness of the software's human-machine interface. At the same time, the advantages of each software are combined, and other software is used as auxiliary. When using, the 3D model can be converted into a unified format. During the 3D modeling process, due to operational reasons and high precision requirements for the built model, a large number of redundant points, lines, and surfaces may be generated in the final modeling results. Exporting a 3D model from software will generate a large amount of data, and importing it into simulation software will consume a lot of computer memory. At the same time, during the operation of the virtual simulation system, there may be problems such as lagging simulation interfaces and incomplete animation display. According to the platform function arrangement in Chapter 3, a typical electrical virtual simulation experimental platform is already quite mature. This article mainly studies the design of an electrical system for an automated production line based on PLC [16].

4.1 Simplification of the Model

This article uses the method of converting 3D models into 3DXML format to achieve lightweighting of 3D models. As shown in Fig. 4, the 3DXML file is in multi document mode, and a complete 3D model saved will be scattered in files with 3dxml and 3drep as file name suffixes. Finally, use ZIP algorithm to compress it into a file, with the extension Manifest being the file name containing the assembly information, and 3drep being the file name containing the model's graphic data and its own attribute information. Unlike typical CAD files, 3DXML does not contain geometric information and only includes solid information of 3D models and assembly features of mechanical structures. Therefore, Manifest can reduce storage space by 90% compared to typical CAD file formats.

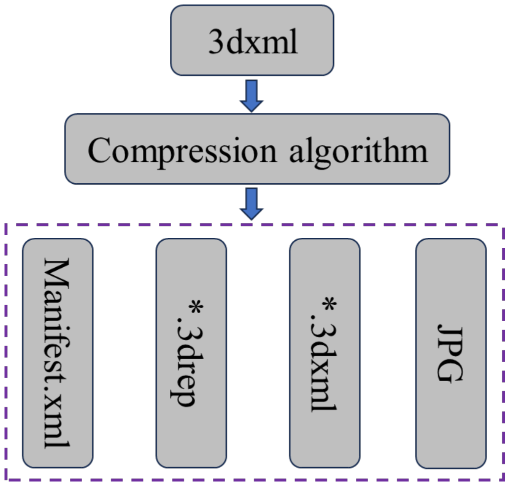

Fig. 4. Flow chart of virtual simulation training process

This article uses SolidWorks for 3D model modeling, which supports 3DXML format. After format conversion, it is imported into simulation software. In response to the large amount of redundant information generated by the modeling results, this paper simplifies the model [17].

Generate envelopes in different regions of the model surface, where the envelope refers to generating a bounded enclosing surface, simplifying the mesh under the overall control of each envelope, folding and shrinking the edges of the model, and defining the shrinkage cost ε. For each vertex d in the mesh, establish a 4 × 4 symmetric error matrix M_{error} corresponding to it. The expression of the vertex is:

$$d_i = [x_i, y_i, z_i, 1]^T \quad \textbf{(1)}$$

Assuming the selected target shrinks edge (d_1, d_2) and its vertices become d after shrinking, the error matrix of the new vertices is represented as:

$$M_{error} = M_{error1} + M_{error2} \quad \textbf{(2)}$$

The expression of the error function is:

$$\varepsilon = d_i^T M_{errori} d_i \quad \textbf{(3)}$$

The expression for the error matrix is:

$$M_{errori} = \begin{bmatrix} m_{i11} & m_{i12} & m_{i13} & m_{i14} \\ m_{i21} & m_{i22} & m_{i23} & m_{i24} \\ m_{i31} & m_{i32} & m_{i33} & m_{i34} \\ m_{i41} & m_{i42} & m_{i43} & m_{i44} \end{bmatrix} \quad \textbf{(4)}$$

By organizing the above formula, we can obtain:

$$\begin{aligned}\varepsilon = m_{i11}x_i^2 + 2m_{i12}x_i y_i + 2m_{i13}x_i z_i + 2m_{i14}x_i + m_{i22}y_i^2 \\ +2m_{i23}y_i z_i + 2m_{i24}y_i + m_{i33}z_i^2 + 2m_{i34}z_i\end{aligned} \quad (5)$$

The process of taking partial derivatives of x_i, y_i, and z_i in the above formula is as follows:

$$\frac{\partial \varepsilon}{\partial x_i} = \frac{\partial \varepsilon}{\partial y_i} = \frac{\partial \varepsilon}{\partial z_i} = \begin{bmatrix} m_{i11} & m_{i12} & m_{i13} & m_{i14} \\ m_{i21} & m_{i22} & m_{i23} & m_{i24} \\ m_{i31} & m_{i32} & m_{i33} & m_{i34} \\ 0 & 0 & 0 & 1 \end{bmatrix} d_i = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \quad (6)$$

After folding and shrinking the edges, the position of the new vertex is expressed using the following formula:

$$d_i = \begin{bmatrix} m_{i11} & m_{i12} & m_{i13} & m_{i14} \\ m_{i21} & m_{i22} & m_{i23} & m_{i24} \\ m_{i31} & m_{i32} & m_{i33} & m_{i34} \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \quad (7)$$

Therefore, through the above process, the model can be simplified, and the processed model will avoid redundant points, lines, and surfaces.

4.2 Construction of PLC Virtual Simulation Environment

In the simulation stage of this article, Mitsubishi PLC is selected. Mitsubishi PLC is mainly used for automation control in the industrial field and is one of the mainstream controllers in the market. It can accept input signals from sensors, actuators, control panels, and other devices. This article uses FX5U-64MR/ES PLC as the research object for data acquisition and virtual debugging of digital twin production lines. The PLC adopts high-performance CPU modules and is equipped with efficient power supply and output relays. Supports external interfaces such as Ethernet and RS-485. Mitsubishi Electric's GX Work3 is a powerful engineering software that provides comprehensive support for the development of PLCs and HMIs, meeting user needs from program design, debugging to maintenance. GX Works supports various PLCs such as Mitsubishi FX5U, L series, Q series, etc. Supports multiple programming languages such as ladder diagrams, function diagrams, structured text, etc. This article uses GX Works3 (version 1.0) to study data communication and acquisition for PLC program design and virtual debugging. GX Simulator is a PLC simulation software launched by Mitsubishi Electric, which can simulate the operating environment of PLCs. Unlike GX Works, GX Simulator is specifically designed for PLC simulation, providing a more realistic and complete simulation environment. This article uses GX Simulator (version 3.0) to simulate FX5U PLC. MX Component is a component developed by Mitsubishi Electric for implementing communication between computers and PLCs. It provides rich API functions to facilitate read and write operations on PLCs, and supports multiple communication protocols such as serial port, Ethernet, USB, etc.

Import the uncompressed ladder diagram project in GX Works3, select the "Debug Simulation Start" command, open GX Simulator3, and wait for the FX5U program to write into the simulator. Run the MX Component Communication Setup Utility as an administrator, as shown in Fig. 5, to create a new logical station port for the virtual PLC. Set the station number to "0" to ensure the independence of PLC task execution and ensure that the PLC executes different tasks simultaneously. As shown in Fig. 5, the PC I/F is set to GX Simulator3, the CPU model is FX5U, and the custom port number is "5511". The timeout limit for a single operation is 10000 milliseconds, and the configuration of virtual PLC simulation parameters has been completed [18].

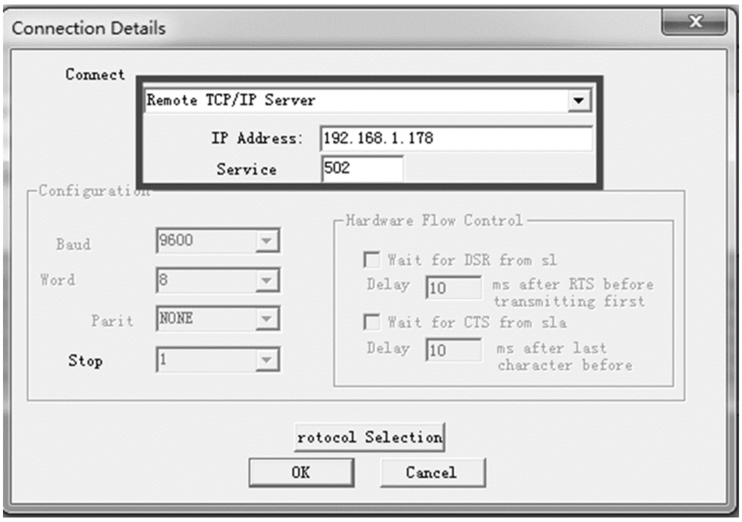

Fig. 5. Virtual simulation PLC parameter setting interface

In GX Works3, configure and create a PLC project for virtual environment communication testing, as shown in Fig. 6. Create a new project, add the FX5U PLC device, and select the CPU model as FX5U-64MR/ES. Use the Communication Test module of MX Component to test the simulated communication with logical station number 0. The display configuration simulation has established preliminary communication connections, proving the successful simulation of the simulation environment.

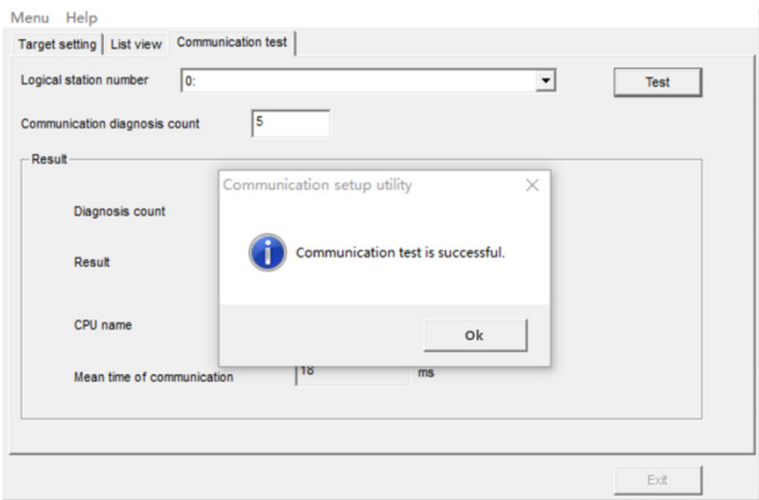

Fig. 6. Setting up communication links

4.3 Implementation of Typical Equipment Scenarios

Typical equipment scenarios include the framework, transmission equipment, and sensors of electrical training equipment. The electrical equipment in simulation scenarios mainly includes mirror reflection photoelectric switches, reflective photoelectric switches, and other photoelectric sensors. The framework mainly includes the overall structure and transmission device, while the transmission equipment mainly includes motors and gears.

1) Mirror reflection photoelectric switch is one of the main interactive electrical devices commonly used in building automated stereoscopic warehouse control systems, consisting of a light source emitter, a light source

receiver, and a reflection plate. Under the action of the reflector, the receiver can receive the photoelectric information emitted by the transmitter. Due to the fact that the receiver needs to receive the photoelectric information emitted by the transmitter through the reflection effect of the reflection plate, the system will promptly control the switch when there is a detected object blocking the optical path.

Firstly, create an empty object named Trigger as a sub object of the mirror reflection photoelectric switch simulation model. Add Box Collider and Rigid body components to the Trigger empty object and select the 'is Trigger' option. Click Edit Collider to adjust the collision enclosure to the appropriate size, as shown in the green cube in Fig. 7, and use it as a trigger to simulate the function of mirror reflection photoelectric switch.

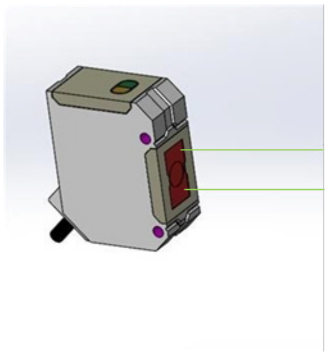

Fig. 7. Creation of photoelectric switch model

Create a new trigger script and write a collision detection function, and add it to the empty Trigger object. In the simulation scene, arrange the lens model according to the activity path of the mirror reflection photoelectric switch, and the triggering principle of the trigger is shown in Fig. 8. When the lens is outside the collision range, the photoelectric switch has no response. When the lens enters or leaves the range of the collision object, the collision object is detected, and the collision detection functions On Trigger Enter and On Trigger Exit are executed, calling the data writing function.

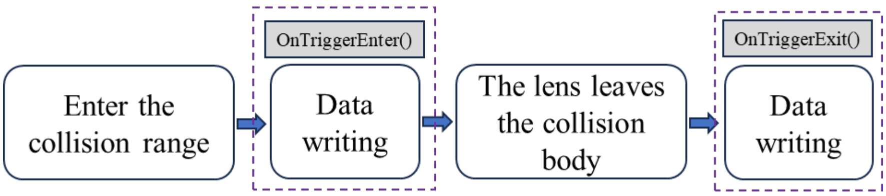

Fig. 8. Schematic diagram of departure principle

2) As a simulation object, the conveying device is divided into left conveyor and right conveyor in the simulation scene. The left conveyor is responsible for conveying goods to the stacker crane, while the right conveyor is responsible for sending out the unloaded goods from the stacker crane. The left and right conveyors are divided into two parts: drum conveyors and loading conveyors. Taking the left conveyor as an example to illustrate the development of the conveyor simulation function. As shown in Fig. 9, the left side of the conveyor is a drum conveyor, and the right side is a loading conveyor. A collision enclosure is created at the left end of the drum conveyor and the right end of the loading conveyor as triggers, and the trigger creation method is described above. When the goods are generated at the left end of the roller conveyor, they come into contact with the collision shaped enclosure, triggering the drum to rotate and transport the goods to the right. When the goods are transported to the right side of the loading conveyor and come into contact with the collision shaped enclosure at the right end of the conveyor, the right trigger is triggered, the drum stops rotating, and the goods stop being transported and wait for the stacker crane to pick them up.

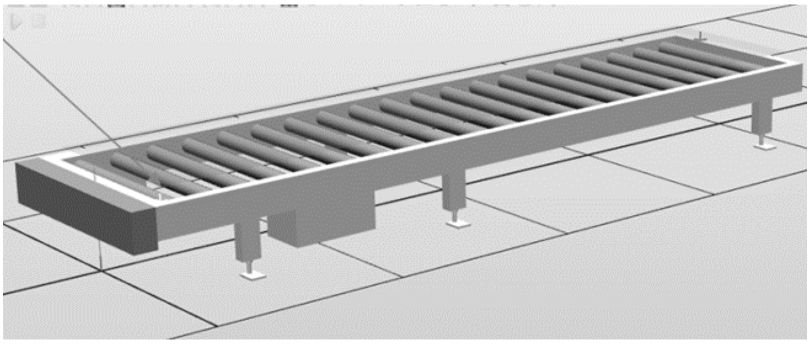

Fig. 9. Belt modeling

3) Modeling of servo motor, the main components of servo motor include bearings, base, housing, etc. Taking the bearings of servo motor as an example, the model and proportional dimensions parameters are shown in Fig. 10.

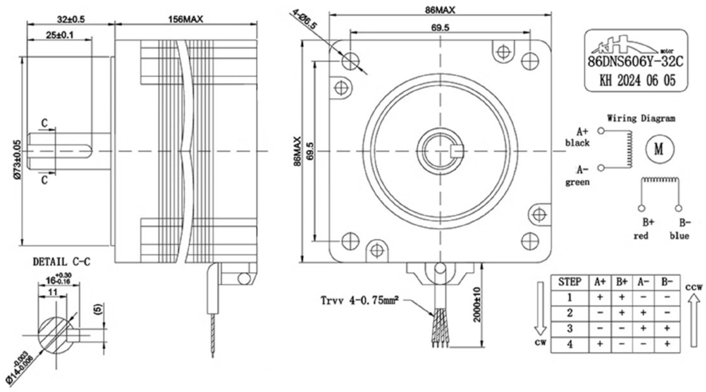

Fig. 10. Modeling of servo motor

Based on the parameters of the servo motor, use SolidWorks software to establish a model of the servo motor. According to the above servo motor modeling process, it includes disassembly, drawing, assembly, etc. of servo motor parts. The established model is shown in Fig. 11.

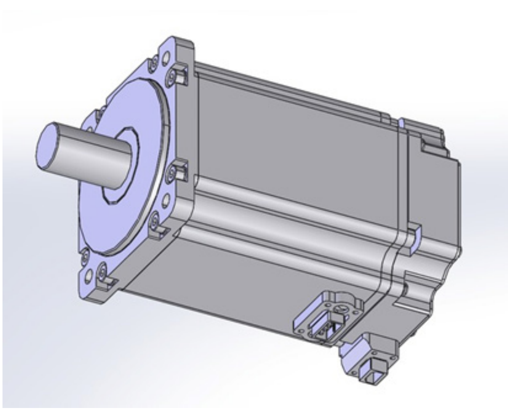

Fig. 11. Establishment of servo motor model

In Unity3D, we can use the Transform component to load the model. In Unity3D, the Transform component plays an important role in managing the positioning, orientation, and size of objects in the scene. By modifying the attribute values of the Transform component, it is possible to perform operations such as translation, rotation, and scaling of simulated objects, thereby achieving rich control interaction and visual effects. In addition, the Transform component can control the parent-child relationship between objects. By setting the parent attribute, one object can become a child object of another object. The Transform component establishes a parent-child relationship between model objects. Through the parent-child relationship of the Transform component, the combination and hierarchical structure of various parts model objects of the servo motor can be realized. For example, one part model object can be used as a sub object of another part model object to form complex game scenes and interaction modes. The Transform component in Unity3D has three properties: position, rotation, and scale, which control the position, rotation, and scaling of the simulated object [19].

After importing the servo motor model into Unity3D, proceed with scene layout. When setting up a scene in Unity3D, the first step is to design the lighting, which is based on the principles of lighting design. In Unity3D, lighting design is a key component in creating realism and atmosphere. Lighting design can change the atmosphere of the scene and the appearance of characters, making simulation effects more vivid and realistic. In Unity3D, lights can be placed by adding them to GameObjects in the scene. In addition, multiple lights can be arranged in the scene and their position, rotation, and properties can be changed to achieve the desired lighting effect. Finally, testing and optimizing the lighting. After placing lights in the scene, testing and optimization are required to ensure the performance and quality of the simulation. You can use the Profiler tool provided by Unity3D to analyze the performance of lighting in the scene. You can also use the rendering path provided by Unity3D to control the quality and performance of the lighting [20].

After the above process, the construction of the virtual simulation model in the training platform has been completed. This chapter selected typical electrical components for the analysis of the simulation modeling process. The modeling principles of other components are the same, so a complete simulation environment can be established based on this method.

5 The Application of Simulation Training Platform in Courses

The application research of this teaching implementation was carried out in the actual courses of our university. The software and hardware facilities of our university basically meet the implementation requirements. Both teachers and students have good information literacy and professional ethics, and have a certain level of electrical technology. They also have some understanding of blended learning. In order to verify the application effect of the electrical training teaching platform constructed in this article in the practical course of "Electrical Technology Application", this article uses the widely used hybrid online and offline teaching application scheme in the current education mode to verify the effectiveness of the platform constructed in this article, and illustrates the effect through actual teaching applications.

The training platform constructed in this article can complete boring transmission and grasping, download engineering projects to virtual PLC, start MCD simulation, perform input and output operations on HMI, and observe the motion changes of corresponding axes in the MCD model. The changes in variables can be monitored online in TIA and MCD. In MCD, variables can be added to the "Run Viewer", and in TIA, variable trend charts can be generated through trace or added to HMI for observation. After completing the hardware configuration, connect the PC to the system via Ethernet and download the TIA project to the physical PLC for debugging. Operate the three-axis device through I/O input/output external switches in the hardware device and buttons on the HMI, observe the accuracy of three-axis motion, mechanical gripper zeroing, and fixed-point material grasping in the device, and analyze errors for improvement. The model designed based on NX software electromechanical concept cannot directly exchange data with physical PLC through Ethernet and needs to be transmitted through OPC UA server.

5.1 Manual Control Experiment for Material Conveying

After the modeling process in Chapter 4, the coordinates of the materials on the conveyor belt can be obtained in real time through the download of the PLC virtual program. The coordinates are converted and corrected into three-dimensional spatial coordinates, and the information is transmitted to the robot. At this time, the PLC controller drives the three-axis grasping device to grasp and classify the placement according to the three-dimensional spatial coordinates. Place the material at position (349,256,160). The material coordinates recognized by the automatic sorting system are (358,239,160), and the PLC control program is shown in Fig. 12.

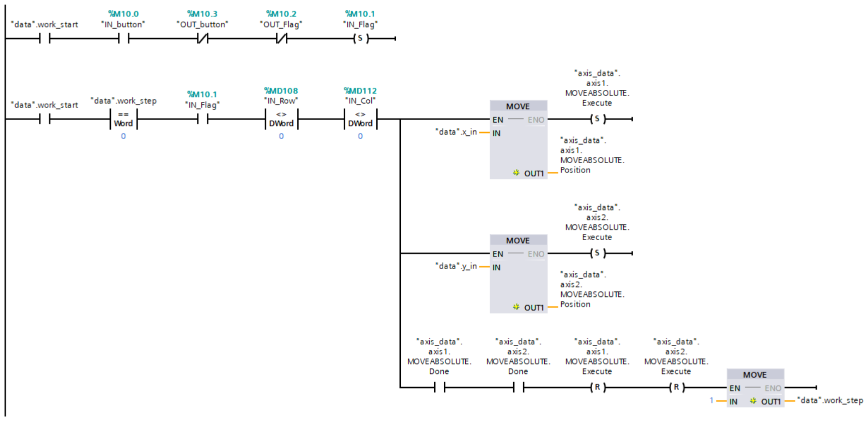

Fig. 12. PLC control program

During the material transportation process, the coordinate transformation of the material is shown in Fig. 13. Through coordinate transformation, the robot's pose can be controlled.

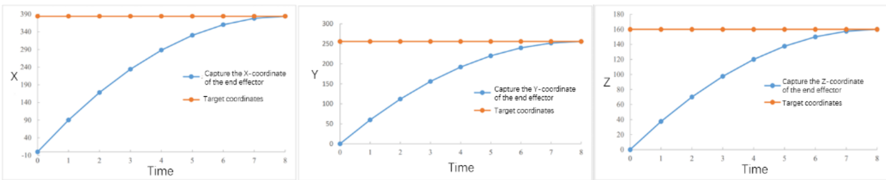

Fig. 13. Change in material coordinates

5.2 Virtual Scene Roaming

In order to achieve the functionality of the PLC electrical system teaching platform and enable experimenters to observe the operation status of the PLC controlled production line more intuitively, a scene roaming function is set up. Scene roaming is achieved through the keyboard W, A, S, D, Q, E keys, and the mouse wheel is controlled to zoom in and out of the model. In Unity3D, taking PLC control to complete the transportation and grasping of raw materials to be processed as an example, it is necessary to first add a collision device Sphere Collider to the end tool head of the robot to form a surrounding ball. Secondly, it is necessary to add a Box Collider collider on the blank model to form a bounding box. Then it is necessary to add a rigid body component for both collision parties to simulate the effect of physical collision. Finally, write code in C # language to complete the test. The code is as follows:

```
Use this for initialization
void Start ()
private void OnCollisionEnter(Collision collision)
{
  Debug.Log;
 }
private void OnCollisionExit(Collision collision)
{
```

```
    Debug.Log;
  }
  private void OnCollisionStay(Collision collision)
  {
    Debug.Log;
  }
  Update is called once per frame void Update ()
  { }
```

The experimental results of the electrical platform are shown in Fig. 14.

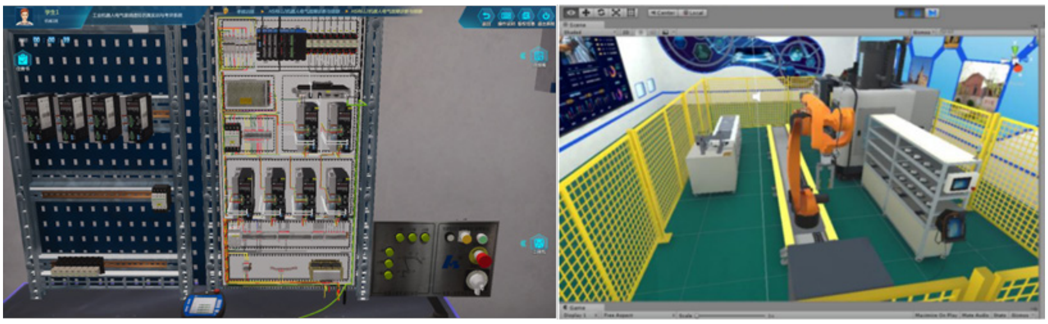

Fig. 14. Typical learning resource display

5.3 The Use of Simulation Training Platform

Through the "Task Case Practice" learning activity, similar practical situations are created for students to conduct experiments, as shown in Fig. 15. After demonstrating and explaining the typical electrical application control operation process on the simulation training platform, the teacher adopts the "group discussion and mutual evaluation" learning activity to conduct practical operations according to the platform's divided groups. Each group selects a team leader to be responsible for the overall organizational work. Each group is encouraged to collaborate with group members to complete practical hands-on tasks. After completion, the group members are guided to discuss the problems encountered and exchange their own views. Then, each group sends a representative to summarize and speak, and the teacher provides guidance and grading based on the overall situation. Finally, the students' learning effectiveness is tested by assigning experimental report assignments.

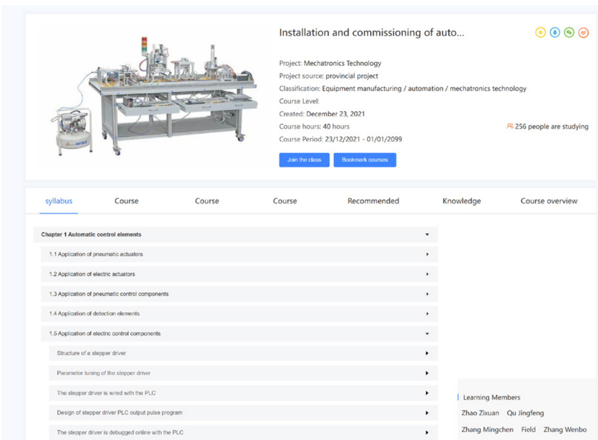

Fig. 15. Virtual simulation training effect diagram

5.4 Feedback on Virtual Simulation Training Courses

After the end of the semester, a questionnaire survey was designed to investigate the learning effect of the practical teaching platform application plan, taking the practical course of "Electrical Technology Application" as an example. The survey included students' attitudes towards blended learning based on the practical teaching platform, teaching platform survey, student satisfaction with learning, learning effect, existing problems, etc [21]. The collected data was statistically analyzed. A total of 67 questionnaires were distributed and 64 were collected, with a response rate of 95.52%. The statistical results of the survey questionnaire are shown in Fig. 16.

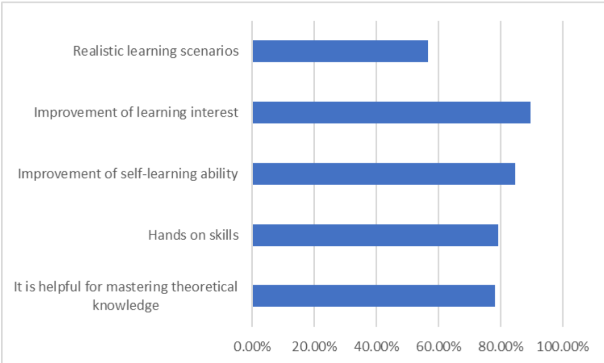

Fig. 16. Statistics of survey questionnaire results

Through questionnaire statistical analysis, it can be found that in terms of acceptance attitude, 78.3% of students believe that theoretical knowledge is helpful, 79.2% believe that hands-on ability can be improved, 84.7% believe that self-learning ability can be improved, 89.6% believe that learning interest can be improved, and 56.6% believe that it is close to real scenarios. The practical teaching platform is relatively suitable for the implementation of blended learning teaching in the practical course of "Electrical Technology Application", indicating that most students have a high degree of acceptance of this teaching method.

6 Conclusion

This article addresses the practical problems of insufficient offline training equipment, single training scenarios, and inflexible expansion of training equipment in universities. Firstly, based on the current shortage of training equipment and the explosive demand for virtual simulation training platforms in universities, an analysis of the virtual simulation requirements for electrical systems and the construction of an overall virtual simulation experimental system framework are conducted; Then, based on specific training projects, the process of building virtual simulation experiment scenes was introduced, and the models and data processing schemes between models were completed; Finally, based on the constructed course platform, the course tasks were completed in real classrooms and positive feedback was received.

The development of comprehensive training programs not only meets the talent needs of current enterprises, but also cultivates students with improved work abilities. The PLC practical training project that students learn in school is often used in practical work, which greatly shortens the time for talent cultivation in enterprises. The increase in comprehensive PLC training programs has avoided the issue of repetition in some universities and colleges regarding PLC training programs. The developed practical training projects not only meet the needs of social and professional positions, but also cater to the needs of students' career development.

In vocational schools abroad, especially in Germany, the training of vocational workers is a typical example, and their curriculum development is career oriented. Therefore, whether it is the development of other courses or the development of practical training projects, they should not be divorced from the actual work of the enterprise. Based on the actual employment situation of the enterprise, utilizing various social resources to develop practical training projects based on the work process is the key to the development of online training courses. Only by closely linking classroom teaching with practical work processes can students improve their core vocational skills and employment competitiveness. In the process of practical training, the guiding teaching method should always be student-centered and teacher assisted. We should fully utilize the comprehensive functions of the on campus training rooms and make full use of the cooperative relationship between the school and enterprises. The PLC training program jointly developed by schools and enterprises will not only improve students' vocational and technical abilities, but also enhance the advantages of talent cultivation in the college. In the stage of developing practical training projects, in order to ensure the vocational orientation of vocational education and training courses, enterprises should participate in the development of PLC practical training projects.

Due to regional differences, each school is setting training objectives based on local development. Lack of interdependence and continuity between each other. There is a lack of communication and research on the development rules of PLC course training projects among universities. At the same time, there is a lack of consideration for students' sustainable development in the development of PLC training projects.

At the same time, the future research directions of this article are summarized as follows: (1)for the development of comprehensive PLC training projects, more practical applications should be used to expand PLC training projects and optimize the design of training projects; (2) The investigation into the demand for PLC application talents in enterprises should be more in-depth; (3) In the school PLC training project, a development team mainly composed of experts and teachers should be formed to continuously enrich and evening training tasks, keep up with the times, and closely follow the current technological development trend.

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References

[1] Y. Li, J.-L. Zhang, X. Rao, Y.-Y. Zhou, T. Li, Construction and Practice of Virtual Simulation Experiment Teaching Platform in Universities Based on Digitization, Research and Exploration in Laboratory 42(10)(2023) 233-238.

[2] Y. Zhou, W.-N. Zhang, Construction of Hardware-in-loop Simulation Training Devices for Course of Electric Control and PLC Technology, Research and Exploration in Laboratory 36(7)(2017) 230-234.

[3] X. Tong, Y. Xiong, Application of Simulation Technology in the Course of Electrical Control and PLC, Application of IC 39(12)(2022) 82-83.

[4] G.-D. Cheng, Design of Electric Control Training Platform Based on PLC, China Modern Educational Equipment (23)(2022) 55-57. DOI: 10.19339/j.issn.1674-2583.2022.12.030.

[5] L.-X. Yu, Design of Experimental Teaching for Electrical Control and PLC Application Course, Application of IC 40(11)(2023) 386-387.

[6] Q.-H. Liu, Teaching research of electrical control and PLC technology based on simulation technology, Woodworking Machinery (4)(2023) 37-39+48.

[7] M.-C. Hao, J.-Y. Ren, Y.-Z. Qiao, The Application of Virtual Simulation Technology in the Practical Training of Sensors and Detection Technology Course, Information Science and Engineering Research 4(6)(2023) 44-48.

[8] H. Li, Y. Wei, J.-Y. Zhong, Y.-F. Chen, S. Qian, W.-T. Yue, Teaching Practice of PLC Programming in Elevator Virtual Simulation Experiment Platform, Contemporary Education and Teaching Research 5(2)(2024) 67-72.

[9] J.-L. Ma, W.-Z. Li, T. Qin, Design of Training Platform for Collaborative Manufacturing of Machining Center and Industrial Robot, Sci-tech Innovation and Productivity (5)(2020) 54-59.

[10] C. Zhang, F. Lin, J. Wang, H.-H. Si, Design and implementation of PLC configuration virtual simulation system based on WebGL, Computer Era (12)(2022) 9-12+16. DOI: 10.16644/j.cnki.cn33-1094/tp.2022.12.003.

[11] R.-Z. Li, Z.-W. Wu, S. Cheng, Exploration on Experiment Teaching Reform of Electrical Control and PLC Technology in Application-Oriented Undergraduate Colleges Under Background of New Engineering: Taking Shanxi Institute of Energy as Example, China Educational Technology & Equipment (10)(2023) 142-145+149. DOI: 10.3969/j.issn.1671-489X.2023.10.142.

[12] L.-Y. Yu, Y.-X. Li, Y.-J. Shi, Z.-Y. Hou, Y.-H. Wu, K.-R. Chen, Y.-Z. Guo, Virtual Simulation Teaching Platform for Design and Analysis of Brake-by-Wire System, Experiment Science and Technology 21(6)(2023) 41-47.

[13] Z.-C. Li, Q.-Y. Kong, H.-N. Wang, T. Xiong, L. Zeng, Construction of Electrical Control and PLC Multi-level Practical Teaching Platform, Research and Exploration in Laboratory 39(11)(2020) 212-215.

[14] Z. Liao, M. Yao, X. Yu, J.-M. Huang, Design and Implementation of High Availability of MySQL Database Based on Keepalived and Mycat, Modern Information Technology 6(11)(2022) 27-29+33.

[15] J. Ma, Y. He, X. Li, L.-G. Niu, Y.-C. Ji, R. Wang, Research on college experimental online teaching system based on

virtual simulation technology, Modern Electronics Technique 45(11)(2022) 125-130.
[16] J.-T. Gao, Y. Fang, D.-Y. Hu, X.-G. Song, Y.-Q. Ding, Train electrical simulation system based on Virtual Reality, Intelligent Computer and Applications 9(4)(2019) 154-158.
[17] X.-K. Xia, C.-M. Liu, K.-Y. Chen, A method for flattening redundancy simplification of 3D models, Journal of Spatio-temporal Information 30(2)(2023) 289-294.
[18] Y.-F. Yuan, T. Yang, Design and implementation of production line simulation system based on virtual PLC, Manufacturing Automation 45(1)(2023) 73-77.
[19] X.-X. Song, Y.-D. Chen, J.-Y. Gu, K.-Y. Cao, X. Zheng, Virtual Disassembly and Assembly Experiment System of Hydraulic Components Based on Unity3D, Microcomputer Applications 38(7)(2022) 7-11.
[20] Y. Luo, Y. Ma, J.-Z. Guo, M.-M. Gao, S. Wang, L. Wang, C.-F. Zhou, Research on Virtual Reality Technology of Unity3D-based Riser Horizontal Welding Robot, Machine Tool & Hydraulics 51(12)(2023) 171-175.
[21] D. Wang, Y. Gao, Design of Questionnaire based on Quality Analysis and Problems to be Noticed, Quality Exploration 16(4)(2019) 77-81.