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Development and System Design of Intelligent Training Platform for Universities Based on Internet of Things Technology

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Abstract. Starting from the requirements of the practical training process, this article uses the existing training platform as the hardware equipment foundation to complete the overall design of the training platform. The existing training equipment has been extensively researched and analyzed using hardware modules provided by Huibo Robot Integration Co., Ltd. Based on specific production functions, the combination installation of equipment can be achieved. This article selects the console module, tool library module, execution unit module, polishing module, trajectory drawing module, and sorting module to form the hardware equipment. With the core technology of flexible manufacturing system as the support, a complete flexible manufacturing training system that simulates the production line process is built. The article will design the lower computer software and configure three main tasks to control multiple motors. Then, the upper computer software will be designed to complete human-computer interaction, task editing, and communication functions. Finally, the control software for the robotic arm will be developed, and the main function task action function framework will be designed to achieve module reorganization of the robotic arm software. Finally, the design of the training system will integrate virtual reality and digital twin technology to achieve remote control of the equipment, remote acquisition of experimental data, and remote viewing of the actual equipment operation status. In the remote video viewing function, visual automatic tracking technology is integrated to ensure that the main functional modules are visually captured and displayed during the digital twin debugging process. The feasibility of the method proposed in this paper has been verified through experiments.

Keywords: Internet of Things, remote debugging, intelligent debugging

1 Introduction

Practical training is an important teaching content in vocational colleges and an important means of cultivating skilled talents. The informatization and intelligence of practical training course management are powerful guarantees for vocational colleges to carry out practical training teaching. Traditional practical training courses rely on real-life training equipment and venues for practical teaching, while offline training venues and equipment are far behind the current technological development speed of factories, resulting in training content that cannot match production scenarios [1]. At the same time, most universities do not have the ability to purchase sufficient training equipment, let alone ensure that equipment is updated according to technological development. This leads to offline training teaching being constrained by practical factors such as venue and time, resulting in students being unable to participate in training exercises and obtain the expected training effects. Some training projects that require cooperation with factories and enterprises are also hindered by time and space factors [2].

Virtual simulation technology has been widely applied in practical training due to its ability to be performed by multiple people on multiple computers over multiple time periods. However, compared to real offline training equipment, virtual simulation technology also has its own shortcomings, mainly including:

1) It cannot completely replace actual operation. Although virtual simulation experiments can provide a cer-

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tain practical experience, they cannot completely replace real experiments. The data transmission and processing of training equipment during the training process are not clearly reflected in the virtual simulation process. Since the equipment does not exist in reality, the status data of the equipment does not exist and cannot form real data feedback.

2) In terms of operational experience and visual effects, there is a huge difference between the operating status and results of virtual simulation devices and real devices, which cannot allow students to truly experience the operating status of the devices.

3) Virtual reality technology relies on simulation models of systems and hardware, and all simulation mechanisms are idealized and simplified based on textbook materials for existing equipment and systems. However, real training equipment may encounter various occasional situations, unconventional phenomena, and interference factors during use and practice, which require high technical proficiency and experience from users [3].

Digital twin technology weakens device characteristics and mainly focuses on operational data. By constructing multidimensional virtual models that are consistent with physical entities and fully integrating production process data, historical operational data, application service data, and other factors from the manufacturing site, it drives physical entities to complete real-time mapping in the virtual space, thereby reproducing the production activities of physical equipment in the virtual space. It uses derived data to intelligently adjust the production process. Digital twin truly integrates people, machines, and objects through a closed-loop operation mechanism of perception analysis execution feedback. Precise virtual real mapping and dynamic real-time interaction are the two major features of digital twin, and digital twin provides a new idea for data acquisition and transmission [4].

Therefore, based on the above functional technologies and the real needs of vocational colleges for practical training teaching, this article designs an intelligent training platform based on IoT and artificial intelligence technology. Through this platform, not only can virtual simulation operations of devices be achieved, but also monitoring data of real devices can be obtained. At the same time, the real operating status of devices can be observed through remote vision, and as the devices operate, the operating details of the display devices can be automatically captured. Therefore, the research content of this article is as follows:

1) Firstly, the demand for training platforms in vocational colleges was analyzed, and then the existing training platforms were used as the hardware equipment foundation to complete the overall design of the training platform through modular combination.

2) This article integrates the features of virtual reality and digital twins into the training process, while incorporating them into the visual system. That is, when the training process begins, students can complete operations in virtual devices, obtain real-time data through digital twins, and then remotely capture the operating status of on-site devices through vision.

3) Studied the capture and tracking functions of the visual system for key operating equipment, such as automatically aligning the visual focus with the relevant structures and completed actions of the robotic arm when it moves.

In order to better complete the technical aspects described in this article, the chapter layout mainly includes the following settings: Chapter 2 mainly analyzes existing research results and provides research methods and ideas as references; Chapter 3 analyzes the training needs and designs the simulation training platform according to the training needs; Chapter 4 is the design of the training system, which mainly adds visual automatic capture and tracking functions to ensure that students can synchronously observe the operation status of the equipment while performing virtual simulation operations. Chapter 5 is the experimental phase, which verifies the feasibility and implementation effectiveness of the simulation training platform. Chapter 6 is the conclusion section, which summarizes this article.

2 Related Work

The development of IoT technology is relatively mature, and the existing IoT technology mainly realizes the monitoring method of on-site equipment, which has reached maturity. Wei Zhang, based on the traditional valve well design and combined with production needs, proposed an emergency shut-off valve for valve wells that combines flow measurement, information collection, gas concentration detection and other functions. At the same time, in order to solve the problems of real-time monitoring, data acquisition, fault alarm, valve position display, remote cut-off operation, etc. of valve wells, a valve well information acquisition and control integrated device is proposed based on the combination of SCADA system [5].

Yaoyi He analyzed the current situation of coal mine automation and monitoring data collection technology and platform based on ubiquitous perception, industrial Internet of Things, and big data for data acquisition in intelligent mines. He pointed out that the perception nodes lack identity tags, data cannot be shared, system maintenance is difficult, system software is built in a smoke window style, and data fusion is difficult. A smart mining basic information collection process and key technologies based on industrial Internet of Things have been proposed, involving low-power ubiquitous sensing technology, sensing node identity identification and data sharing technology, long-term maintenance free technology, and data hierarchical interaction and fusion technology [6].

Ying Xiao, based on the new generation of information technology, integrates technologies such as the Internet of Things, cloud computing, and data mining to form a modern ecological agriculture IoT monitoring system platform based on cloud computing, and proposes a specific implementation plan for its application in the field of modern agriculture. The application functions and performance of the system were tested through the built testing environment. The results showed that the designed modern ecological agriculture IoT monitoring system based on cloud computing can achieve real-time monitoring of environmental information in agricultural production areas and various production bases, providing users with a good functional experience and performance. It plays an important role in reducing system development costs and ensuring its reliability and security [7].

Shangwu Xiao proposed a mixed resolution monitoring video compression method for facial services, in response to the inability of narrowband IoT to guarantee the transmission quality of facial images in monitoring videos. By utilizing the statistical characteristics of surveillance videos to optimize the speed of face detection, different resolutions are used to distinguish between encoded face and non face regions, improving the recognizability of faces under high magnification compression [8].

In terms of designing a digital twin training platform, Siyuan Chen proposed a MPS intelligent control system and method based on digital twins. Based on the MPS digital twin five dimensional model architecture, analyze its physical MPS, virtual MPS, connectivity, twin data, and service system five dimensional structure. Designed the MPS digital twin intelligent control system framework and elaborated on key technologies such as virtual model establishment, data acquisition, and real-time driving in system development [9].

Shibin Gao, building an intelligent operation and maintenance system for traction power supply based on digital twin technology is a key measure to achieve informationization, digitization, and intelligence of rail transit. Build the physical architecture, information architecture, and model architecture of an intelligent operation and maintenance system with the digital twin network as the core. Based on this, analyze the key technologies for implementing the architecture from the perspectives of holographic perception, information transmission, digital modeling, and operational decision-making [10].

Xuehao Sun, in response to the intelligent requirements of virtual debugging, health management, and performance evaluation of CNC machine tools in intelligent manufacturing, establishes a digital twin implementation framework for intelligent applications of CNC machine tools, proposes a multi domain modeling process for digital twins based on geometric, physical, and data models, and studies key enabling technologies in the construction process of digital twin models; Build a multi-level hierarchical digital twin function implementation framework for CNC machine tools, and promote the implementation of intelligent digital twin applications for CNC machine tools; The digital twin CNC machine tool application system is developed based on the industrial Internet architecture [11].

This article integrates virtual reality technology and digital twin technology, and based on the above research results, completes the design of the basic scheme and the overall design of the system through integration and fusion.

3 Platform Overall Framework Design

The design of the platform framework requires precise integration with the practical training needs in actual courses, as well as the training direction of related professional talents. This article targets students majoring in electrical engineering and summarizes the current training course requirements through comprehensive factors such as course analysis, job requirements, and professional settings as follows:

1) From the perspective of enterprise positions, students majoring in electrical engineering are mainly engaged in quality inspection, assembly, sales, and other positions. For those who inherit research and development and debugging, the proportion of related majors is relatively small. This is mainly due to the short duration of the educational system, insufficient depth of inquiry learning for students, and the lack of teaching hardware resources in schools. As a result, some students have little opportunity to receive specific learning project training, leading

to insufficient teamwork, core practical training ability, and comprehensive practical training ability.

2) From the perspective of professional competence, practical positions generally require electrical engineering students to master basic operational programming knowledge. At the same time, enterprise positions hope that students can cultivate fault analysis and handling abilities, and place greater emphasis on their ability to solve practical problems. They should be familiar with the general process methods of typical industrial robot applications, possess routine maintenance of industrial robots, and have good PLC application skills.

After the above analysis, a qualified student majoring in electrical engineering needs to have rich practical experience and have the opportunity to interact with relevant equipment for a long time. Therefore, this chapter will start from the needs of the practical training process, use accurate demand analysis, and use the existing training platform as the hardware equipment foundation to build the overall structure of the training platform, in order to solve practical problems in the current training process, with the goal of increasing the adaptability and skill level of students in related majors, and increasing the opportunities for individual students to use and familiarize themselves with various electrical equipment.

3.1 Overall Design

The existing training equipment has been extensively researched and analyzed using hardware modules provided by Huibo Robot Integration Co., Ltd. The various functional units in this platform are modular, and can be combined and installed according to specific production functions. This article selects hardware devices such as console module, tool library module, execution unit module, polishing module, trajectory drawing module, sorting module, etc., and uses the core technology of flexible manufacturing system as support to build a complete flexible manufacturing training system that simulates the production line process [12]. The overall framework of the IoT based training platform is shown in Fig. 1.

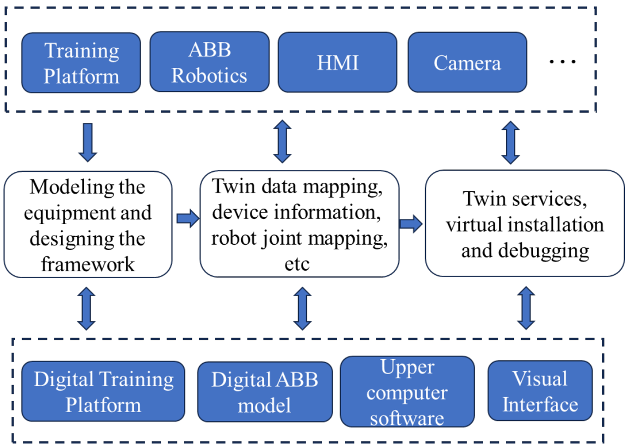

Fig. 1. Framework construction of practical training platform

3.2 Construction of Robot Function Modules

The modeling of virtual industrial robots requires the use of a model tree, which adopts the method of establishing empty objects. The model joints of the industrial robot are taken as sub objects of the empty object, and the coordinate system direction and position of the empty object are kept consistent with the joint model. Geometric modeling visualizes the geometric information of the physical entity, which looks like a robot assembly production line in appearance, but does not describe the physical characteristics of the entity. The physical model considers physical properties such as mass, inertia, material, friction, damping, etc. of the production line equipment based on the geometric model. The design of the model in this article was carried out in SolidWorks software. Based on the measurement of the physical object, the determination of the 2D drawings, and relevant information, the industrial robot model tree was further determined. Base0 and Joint1-Juts6 are empty objects, Base is the base of the robot, and J1, J2, J3, J4, J5, and J6 are the six joint models of the robot, respectively, Base0, Joint1, Joint2, Joint3, Joint4, Joint5, and Joint6 are the parent nodes of Base0, J1, J2, J3, J4, J5, and J6, respectively. Set the Transform value based on the robot linkage parameter information, and ultimately establish the correct parent-child relationship of the virtual model. Draw the various components of the model in the software to improve the motion pair relationship for assembly, thereby obtaining a complete 3D model [13]. The robot model is shown in Fig. 2.

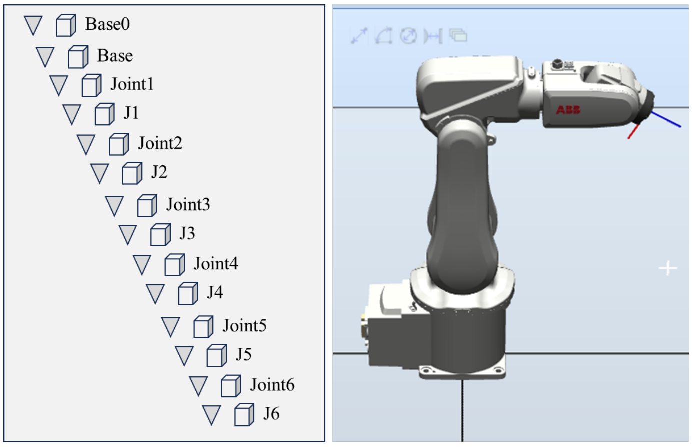

Fig. 2. Industrial robot model

During the driving process of the robot, directional difference is used to achieve consistent motion between the robot and the simulation system robot. The directional difference driving method compares the real-time received positive and negative joint angles with the previous rotation angle, while maintaining the same zero position posture between the virtual robot and the actual robot. According to certain rules, corresponding self increasing or self decreasing behaviors are made, and the value is taken as the angle of rotation of a certain joint in the positive or negative direction relative to the zero position.

This driving mechanism requires the maintenance of four variables, where *n* represents the joint number of the robot; *ChangNum* represents the angle received this time; *RotNum* is a floating-point array that stores the angle of the last rotation and is called in real-time to drive the rotation of the robotic arm; *RobotObj* represents the driven model. The schematic diagram of the principle is shown in Fig. 3.

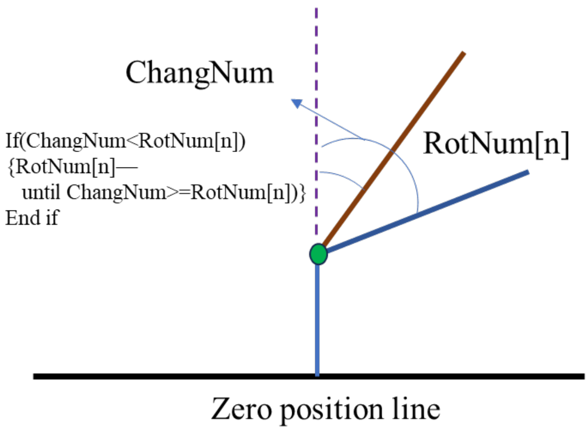

Fig. 3. Schematic diagram of driving model

The algorithm pseudocode is as follows:

Algorithm representation method

Initialize robot joint number n , the angle received this time $ChangNum$, store the last selected angle floating-point array $RotNum$, and drive model $RobotObj$.

```
If ChangNum = 0 then
   If RotNum[n] > 0 then
        ChangNum ← −0.01f
   Else
        ChangNum ← 0.01f
If ChangNum < 0 then
   If RotNum[n] ← RotNum[n] − Time.deltaTime
        If RotNum[n] <= ChangNum then
            Rotnum[n] ← ChangNum
If ChangNum > 0 then
   If RotNum[n] ← RotNum[n] + Time.deltaTime
        If RotNum[n] <= ChangNum then
            Rotnum[n] ← ChangNum
End if
```

3.3 Platform Function Construction

The data feedback and control of the entire system are based on a digital twin system, and the controller of this platform uses PLC. Therefore, the platform needs to have virtual debugging of PLC to quickly write programs to control the production line model. Secondly, the platform based on the digital twin system needs to have status monitoring of the equipment on the intelligent virtual production line. In addition, data generated during the operation of each device is collected and transmitted through data communication protocols. Finally, the twin system designed in this article also has a human-computer interaction mode, which facilitates operators to operate the virtual training platform and make faster judgments on the production status of workpieces. Therefore, the functions of the entire platform system will be elaborated:

1) PLC virtual debugging: In the field of electrical engineering, PLC is a very important controller that requires students to be familiar with its programming language. At the same time, in automated production lines and intelligent virtual training platforms, PLC can serve as a server to write control programs and interact with equipment signals in the virtual platform, facilitating the control of equipment in the production process. In addition, it also supports offline workshop simulation.

2) Data communication: System data is mapped in real-time and can be transmitted after data collection, organization, and processing, ensuring the normal operation of the virtual training platform. The training platform designed in this article adopts OPC UA, TCP/IP, and Modbus protocols, with OPC UA as the main one. OPC UA adopts a client server architecture, supports distributed communication, and provides a strong data model for describing devices and sensors. It also has multiple security options, such as SSL/TLS, X.509 certificates, and Kerberos. It uses binary encoding, has high transmission efficiency, supports custom and extended data types, and supports automatic discovery and configuration of servers and clients.

3) Human computer interaction: The usage of equipment in the training platform should be infinitely close to the real operation process, and start stop interaction buttons can be set to facilitate the control of equipment operation and avoid danger. The equipment includes visual devices, and the functional modules can achieve remote viewing and monitoring of the equipment, realizing visual function monitoring of the training platform from different angles, facilitating monitoring of the processing status of the equipment and observing the training effect.

4) Remote video transmission is achieved through the debugging of production lines in the simulation indus-

try. In addition to being able to run on the simulation interface, real on-site equipment can also achieve synchronous linkage with the simulation interface equipment., This article adopts dynamic bitrate adjustment technology, which can autonomously detect network conditions during video transmission, predict the state based on current and historical network conditions, and dynamically adjust the output bitrate based on the prediction results. When the actual bandwidth is insufficient to support the current video bitrate, the internal encoding module will provide feedback to reduce the video bitrate to ensure smooth video playback and seamless switching of video bitrate. There will be no black screen, stuttering or other phenomena during the switching process, providing strong support for ultra high definition video transmission services.

5) Data return, the data return function draws on the data monitoring technology in digital twin technology. It does not use a separate data interface or window, but synchronizes with the device in reality, providing a more intuitive display of the device's status.

3.4 Communication Network Architecture

The communication network architecture can efficiently integrate all elements, services, and processes of the platform, achieve data sharing within the platform, avoid information silos, and provide complete data support and high-quality information services for the operation of the digital twin training platform [14]. The overall design of the structure is shown in Fig. 4.

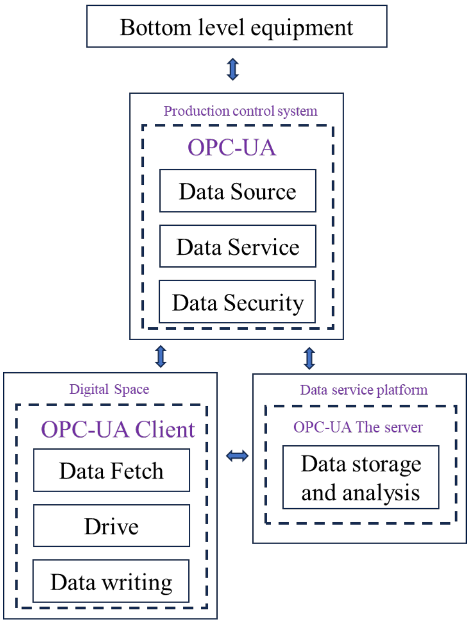

Fig. 4. Overall design of communication network architecture

Create an OPCUA data information module for its internal intelligent virtual production line, where the equipment name, data address, data type, and corresponding functions of the production line are provided by the designer.

3.5 On Site Multi-Target Detection and Tracking

This article uses an improved network model based on YOLOX as the detector for a multi object detection and tracking system during device operation. The system is designed to detect and track multiple functional modules within the camera range in well lit indoor environments. In the complex scene of multi-target pedestrian detection, it is easy to encounter the phenomenon of insufficient target detector capability [15]. Therefore, we will continue to improve it from the aspects of network structure, loss function, etc., to make it more in line with the detection requirements of the system. The improved network model is called YOLOX-P. Introducing attention mechanism in the network, when a certain function in the training function is working, the camera automatically captures the action of that function module and makes appropriate amplification processing for students to observe. The overall framework of improved video intelligent recognition and tracking is shown in Fig. 5.

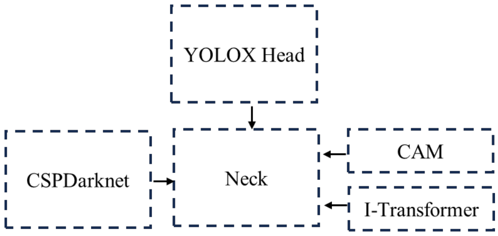

Fig. 5. Multi object detection and tracking

In the framework, the improvement of attention mechanism is mainly reflected in the introduction of channel and spatial fusion attention module. The specific process is as follows: firstly, the input feature map is passed through the channel attention module CAM for global max pooling (MaxPool) and global average pooling (AvgPool), compressing the spatial dimension to 1 and preserving channel information. Then, the two pooled feature maps are sent to a shared multi-layer perceptron (MLP) to extract features. Finally, the pooled features of MLP are added, and the final channel attention weight is obtained through Sigmoid activation function; Afterwards, the feature map undergoes spatial attention module and is subjected to maximum pooling and average pooling in the channel dimension, compressing the channel dimension to 1 and preserving spatial information. Connect the pooled features, extract features through a 7 × 7 × 2 convolutional layer, reduce the channel dimension to 1, and finally use the Sigmoid activation function to obtain spatial attention weights that include channel attention. After completing these two steps in series, multiply the spatial attention features with the original feature map to obtain the output feature map [16].

3.6 Visual Target Tracking

The target tracking algorithm in this article is fused with YOLOX-I and Transformer modules [17], and uses Transformer to mine spatiotemporal contextual information in feature maps to ensure robust tracking. In order to make the classical Transformer structure more suitable for tracking tasks, the algorithm structure is improved by using a decoupled encoder decoder structure and placing it on different trackers. The decoder contains template branch features that are concatenated to form a feature structure group. The expression method of the structure group is as follows:

$$BF\left[i\right] = Concat\left(BF_1, BF_m\right) \in R^{m\times C\times H\times W} \tag{1}$$

The corresponding decoder performs self attention operation on the features of the search branch, and the self-attention mechanism features are:

$$\hat{A} = Ins.Norm\left(A^{'} + A^{'}\right) \tag{2}$$

In the formula, $A^{'} \in R^{m\times H\times W}$, while the template and search branch are calculated separately, there is a lack of information sharing. Therefore, for object tracking, it is crucial for the search branch to learn the target features of the template branch. By using a decoupled encoder decoder structure, the search branch can generate more discriminative features, which can help with object recognition and tracking. The improved Transformer module is shown in Fig. 6.

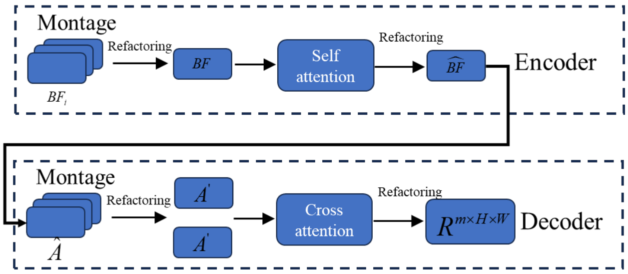

Fig. 6. Improved Transformer module as shown in the schematic diagram

After improvement, this section elaborates on the overall framework design and communication link design of the system. At the same time, in response to the on-site visual tracking design proposed in this article, attention mechanism is integrated into YOLOX and Transformer module is added to achieve tracking of key targets while ensuring visual capture.

4 Design of Training System

The control software of the training platform needs to have the ability to customize tasks, and it is required that the entire training platform, including industrial robot functional links, PLC The programming process and other functional task modules require high-frequency switching during the training process, and the hardware functions of the training platform will also be reorganized based on the switching of virtual modules. Based on the overall design of the entire training platform completed previously, the first part of this chapter will design the lower computer software and configure three main tasks to achieve the function of controlling multiple functional modules. Secondly, this chapter designs the upper computer software interaction system to complete human-computer interaction, task editing, and communication functions. Finally, this chapter will develop the control software of the entire training platform and introduce the development of functional modules for industrial robots as an example. The main function task action function framework will be designed to achieve module reorganization of the robotic arm software. The overall framework of the software system is shown in Fig. 7.

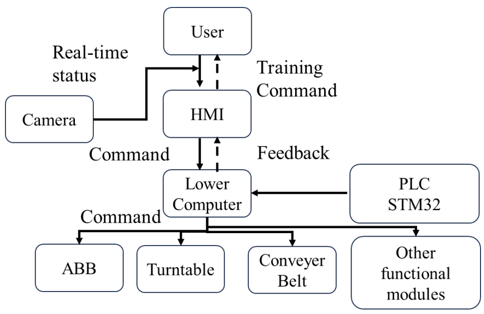

Fig. 7. Overall framework of software system

4.1 System Software and Hardware Design

Flexible equipment should have electrical related professional programming and practical training requirements. Therefore, PLC is selected as the controller for the flexible equipment end. However, as a functional module for on-site video transmission and data acquisition, single-chip microcontrollers are more suitable for data transmission, video data acquisition, transmission, and processing functions. Therefore, STM32 is selected as the equipment for data transmission and data processing in this article. In driver development and operating system development, an integrated development environment (IDE) is required. This project uses Keil's Keil μ Vision5MDK as the integrated development environment.

The main() function is the entry point of the program, and at startup, the μ C/OS-III operating system needs to be initialized first. In current RTOS systems, there are two mainstream startup methods:

1) In the main() function, initialize the hardware driver, RTOS, and create all tasks in the main() function. Finally, activate the task scheduler for task scheduling.

2) The second method is to initialize the hardware and RTOS system in the main() function, then create a startup task to start the scheduler, and then create various application tasks in the startup task. When all tasks are successfully created, the startup task deletes itself. This project adopts the second start-up method. In this project, the main() function first initializes the drivers of each hardware peripheral and initializes the corresponding data. After the initialization of each peripheral and data is completed, the μ C/OS-III system is initialized and a startup task is created. Finally, the μ C/OS-III system is started. In the startup task, when creating tasks, it is necessary to enter the critical zone to prevent interruption, and finally suspend the startup task. The system flowchart is shown in Fig. 8.

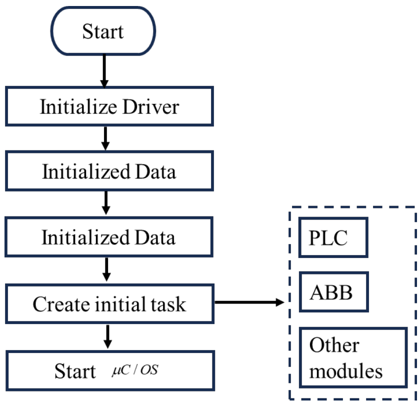

Fig. 8. System flow chart

4.2 Communication Design Between Upper Computer and Lower Computer

The design of the communication link between the upper computer and the lower computer should consider the selection of communication protocols, communication interfaces, programming languages, fault-tolerant handling of data anomalies, packet loss, data errors, and device responses. Therefore, based on the work presented in this article, the communication flowchart between the upper computer and the lower computer in the entire system is shown in Fig. 9.

Use RS-232 serial communication in communication with the upper computer, and use the while (1) function in the communication task function to write the task as a dead loop. In communication tasks, the OSSemPend function is first used to wait for the release of the semaphore. The timeout parameter in OSSemPend is set to 0, which means infinite waiting until the semaphore is obtained and the dead loop is exited. Only then does the task transition from blocking state to ready state. In the serial interrupt service function, when data is received by the serial port, an interrupt is generated and the received data is stored in the data cache area, with the number of data bits recorded. After receiving serial data and bits, the communication task first needs to perform packet unpacking verification. The packet header 0 and packet header 1 in the received data are extracted and compared with 0xFF and 0xAA. If the packet header verification is successful, the sum of each bit is calculated based on the cumulative sum verification method and compared with the verification bit. If the verification is passed, the timeout flag in the SYS structure is set to 0, and the pc_uart_dev-lag flag in the SYS structure is set to 1. After the verification work is completed, the next step is to execute the command from the upper computer. First, the command bit in the packet is extracted, and then the command bit is used to determine the action to be executed through the switch function. The commands sent by the upper computer are mainly divided into two parts. There are two types of commands: parameter setting command and parameter retrieval command.

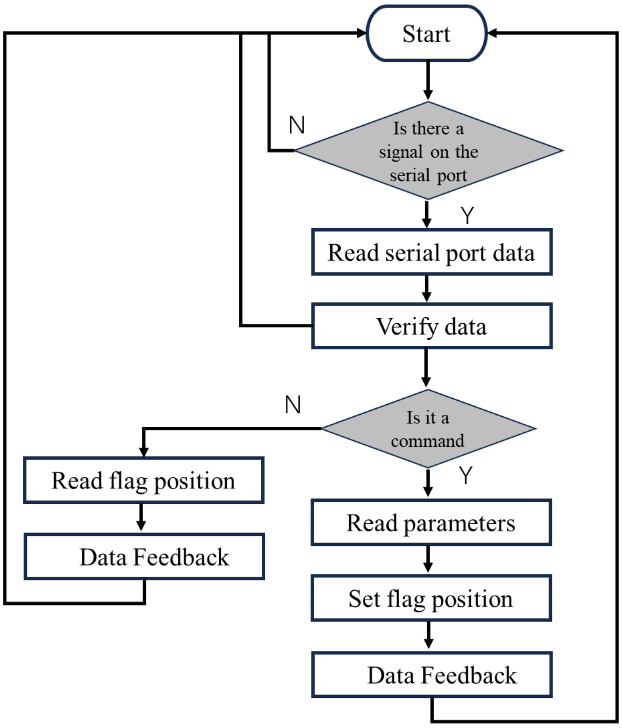

Fig. 9. Communication flowchart

4.3 System Interface Design

The system installed on the upper computer used in this article is Windows 11 Professional Edition, developed in C and C # languages, and developed using Visual Studio 2022, Unity 2020.3.21f1c1 (64 bit), SolidWorks 2020, and Keil uVision5 software. Install the upper computer software designed and developed in this article on the upper computer to select training tasks and set training actions. The interface development of the upper computer control software is based on the Qt platform, as Qt contains a rich function library and good portability. The main interface of this upper computer is shown in Fig. 10. The operation interface of the training platform upper computer is the medium for exchanging information between the system and users, realizing the task of converting internal computer information into a form that operators can accept, and undertaking the function of information interaction. In terms of its functional area, it can be simply divided into “input” and “output”. The interface design of human-machine design follows the principles of object-oriented, sequential, consistency, etc., while also taking into account the aesthetics of the upper computer interface.

The GUI consists of several interfaces, namely the main interface, the create task interface, the add control interface, and the import task interface. The main interface consists of a toolbar, module list, task list, and status list. The toolbar consists of 5 QToolButton controls (i.e. buttons), and the self-test status button is responsible for obtaining the self-test status of each module in the module list after initialization. Based on the self-test status feedback from communication tasks, the icon class in Qt is used to add a cross or cross symbol image to the left side of the corresponding module in the module list. The ‘View Status’ button adds the status of each module obtained from the ‘View Status’ command sent by the upper computer to the status list. The ‘Self check’ button calls the QPixmap class based on the self check status of each module to configure a ‘√’ or ‘×’ image representation in front of each module. The ‘Import’ button reads the task from the previously created and saved JSON configuration file used to express the task to the currTask object for subsequent execution, and displays the specific information of the relevant modules in the task list. The ‘Save’ button is used to save the modified task JSON configuration file locally. The task that is about to be saved to Currtask by pressing the [Execute] button is sent to the training platform and the lower computer through communication tasks via TCP and serial port according to the protocols of the upper computer, training platform, and lower computer to perform relevant training actions.

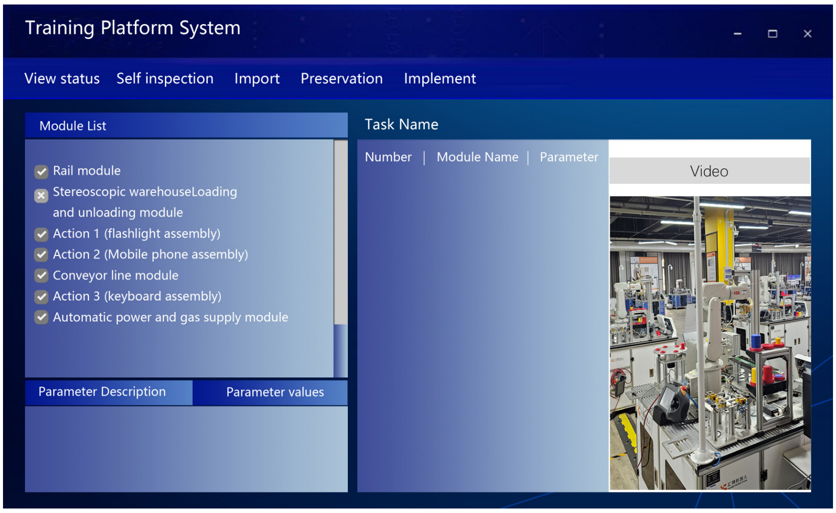

Fig. 10. Upper computer software interface

5 Experimental Results and Analysis

To ensure the smooth operation of the virtual real synchronization control system for the digital twin mobile robotic arm, it is necessary to configure a medium level of computer hardware for graphic rendering related to virtual drilling simulation scenes. The computer hardware configuration for system testing is shown in Table 1.

Table 1. Computer hardware configuration for system testing

Hardware name	Configuration
CPU	Intel Core I7-8600 3.0GHz
Graphics card	RTX 4090
Memory	16GB
Hard disk	1TB
Peripherals	Monitor, hard drive, mouse

The training platform includes ABB robots, model IRB1200-5/0.9, with a working range of 900 mm, a maximum effective load of 5 kg, and 10 signals on the wrist. Choose Siemens S7-1200 PLC, CPU 1211C, and a working memory size of 75kB. The camera selected is a 4-megapixel network camera model DS-2CD2245CV6-I from Hikvision, which uses a 1/2.7 "CMOS sensor and supports ICR infrared arrays. The minimum illumination is 0.005 Lux, and the shutter time ranges from 1/3 second to 1/100000 second. At the same time, the training platform includes other hardware devices and functional modules, which will not be introduced one by one.

5.1 Twin Experiment

The twin experiment mainly verifies the consistency of operation between virtual simulation devices and offline real devices. The results of the twin experiment are shown in Fig. 11.

When conducting verification, the first step is to build the corresponding model in Simulink. The input of the model is the rotation angles of the six joints of the robotic arm. The physical robotic arm control part uses the serial port sending module in the toolbox for data transmission, and the digital robotic arm part uses the TCP module for data transmission, and the model is verified.

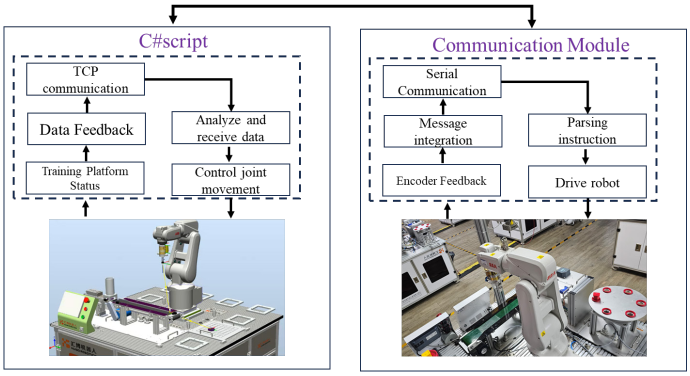

Fig. 11. Twin experimental structure

The essence of synchronous control between virtual and actual robotic arms is to connect the feedback signals of the physical robotic arm and the virtual robotic arm to each other's input interface, thereby achieving mutual synchronization. The controller communicates with the physical robotic arm through RS485 serial port, and interacts with the digital robotic arm through TCP protocol. Both can provide real-time feedback of the current rotation angle to the controller. By building corresponding models for control, the final effect is shown in Fig. 12, and it can be seen that the motion states of the two are completely consistent. The experimental results can be viewed through live video effects.

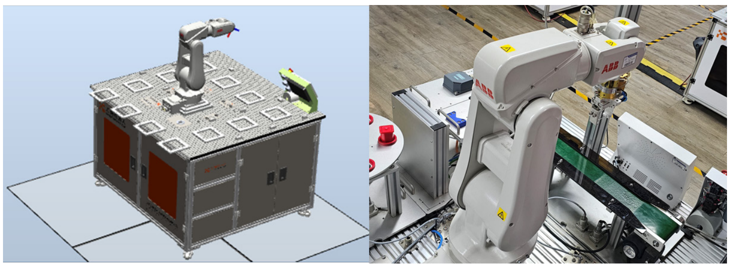

Fig. 12. Synchronization effect display image

5.2 On Site Tool Grabbing Synchronous Experiment and Video Tracking

At the same time, this experimental platform also provides a machine vision based autonomous grasping experiment for robotic arms. By using a camera to recognize the position of objects in the image, the position of the object under the camera is converted into the coordinates of the robotic arm in the world coordinate system. After solving the kinematics and dynamics of the robotic arm in the control system, it is controlled to reach the specified position and perform grasping work.

In terms of experimental verification, the algorithm is written in Python language to process camera information and obtain the three-dimensional coordinates of the object relative to the world coordinate system of the robotic arm after transformation. At the same time, the data is sent through a serial port to facilitate data interaction with the robotic arm drive system. During the sending process, the coordinates are converted to IEEE Binary Floating Point Numbers (IEEE 754) format for string concatenation, and sent via serial port using RS485 protocol. The corresponding device during the experiment is shown in Fig. 13. At the same time, real-time feedback is given on the rotation angles of each motor of the robotic arm, and the real-time position of the robotic arm end effector is obtained by inputting it into forward kinematics. The real-time position is compared with the target position to form a closed-loop control. When the error between the real-time position of the robotic arm end effector and the target position reaches the threshold, it is considered that the robotic arm end effector has reached the predetermined position, and a signal is sent to the gripper for grasping work.

After one click compilation and download of the model through the toolchain, run the target recognition program on the upper computer and run the control strategy model in the robotic arm controller.

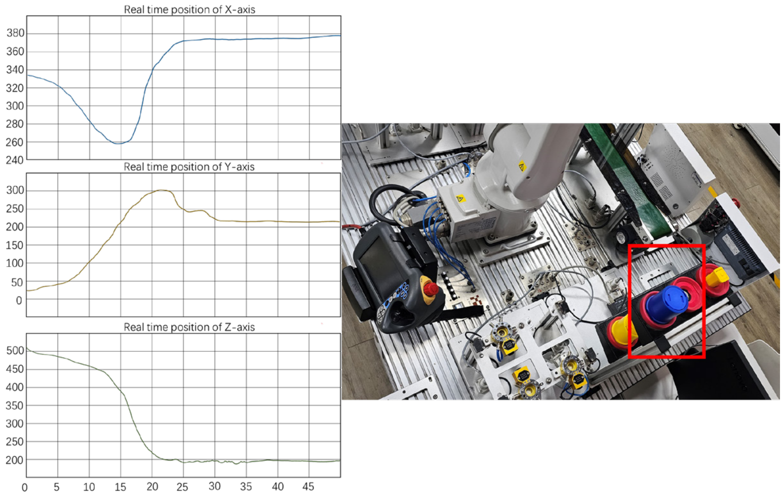

Fig. 13. Coordinate information curve diagram of robotic arm control system

Through the above operations, this article completed a comparative experiment on the twin, control design, and grasping effect of the training design platform and the training platform. The experimental results verified the feasibility of the method proposed in this article, and the visual system can achieve the capture and tracking of specific objects.

6 Conclusion

This article mainly focuses on the modular flexible system developed by Huibo Robot Integration Co., Ltd. as the core hardware for research. Based on a full understanding of the lack of advanced equipment for practical teaching of flexible systems in vocational colleges, this article mainly studies the construction of an automated control training platform. At the same time, in order to solve the problems of on-site training and digital twin training, the following conclusions were drawn through a large number of experiments and analysis in the process of designing the training platform:

1) Mastering the use of industrial Internet of Things in flexible manufacturing teaching training platform, remote IO modules are first added to the execution module, three-dimensional warehouse module, processing module, polishing module, and sorting module of the training system. Then, the remote IO modules of each functional unit module are connected to the PLC of the main control unit, and industrial switches are added to the control device of the main control module. The main control unit PLC communicates with each unit controller and remote IO module through industrial Ethernet to control communication between modules and ensure their normal operation. The process control signals required within the execution unit, the process control signals of the processing unit, all cylinder actions and sensor signals of the polishing unit are transmitted to the main control unit through the industrial network via remote IO modules. Therefore, using industrial Ethernet can facilitate information exchange between products, devices, and controllers.

2) In the past, speed control always used analog control, with sensors detecting actual physical quantities and then transmitting the output analog quantities to the PLC, which converted them into digital quantities. PLC programming is the processing of digital quantities. In this practical training system, the speed control of the slide table is first programmed using digital quantities. The robot sends a group signal to the PLC, and the PLC directly transmits the required speed value using the MOVE command after receiving this signal, greatly reducing the complexity of analog programming, simplifying the program, and making it easy for students to master. The design process is a comprehensive summary of the knowledge learned. Through the research of this flexible

manufacturing training platform, although I have gained comprehensive improvement and exercise, the research process itself is a gradual and upward process, and inappropriate aspects are always unavoidable. Due to limited time, there are still some areas such as communication that can be further studied for this training platform. The application of flexible manufacturing systems will become more widespread in the future, and I hope to make a contribution.

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