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Application of Computer Virtual Reality Technology in Welding Simulation Training of Complex Structures Based on Unity3D

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Abstract: - A virtual reality welding robot simulation system for practical application is developed based on the training and application of welding robot for practical application, which has important theoretical and practical application value for promoting the development of industrial robots in China. The simulation system is synchronized with the welding simulation training platform to achieve the purpose of VR simulation of the welding robot. By modeling the welding process, the process parameters can be inferred automatically, and the digital twin knowledge base for practical application is built. The OPC UA protocol is used to realize real-time communication with mobile devices. The digital twinning technology of CNC machine tool is studied through the simulation experiment of weld motion. This system lays a foundation for realizing the intelligentization of CNC machine tools.

Keywords: Virtual Reality Technology; Welding Robot; Welding Simulation Training; Virtual Simulation Platform; Digital Twin.

I. INTRODUCTION

Digital transformation is the inevitable choice for the country's economic and social development in the future, and the digital twin is the key to achieving this goal. By improving the ability of real-time acquisition, the unification of "virtual and real" and the unification of "virtual and real" are conducive to the effective "fusion" of "virtual and real". In addition, build an augmented reality based on the digital twin, so that users can use the resources of the cloud to obtain the data they need. The essence of digital twin is to realize the combination of virtual and reality, and realize the optimization and prediction of real operation through repeated analysis and analysis of its operating data. However, due to the differences in its research content and application fields, it is necessary to carry out research on digital twin in combination with the current practical needs and key technologies of intelligent automatic welding [1]. In recent years, a number of industrial robot simulation software with good application prospects have emerged in China. For example, the "PCROBSN" developed by Tsinghua University integrates different types of industrial robots and can simulate different types of industrial robots. The "Robot Art" unmanned simulation system independently developed by Chinese airlines can simulate its path based on its self-generated path, and generate corresponding operation animation based on the path. The "ROSIDY" robot simulation system based on AutoCAD developed by Shanghai University focuses on three-dimensional modeling of robots, which has high practical value [2]. At the same time, the major universities in China, the Institute of Automation of the Chinese Academy of Sciences and the famous robot manufacturing enterprises have also carried out the research on robot simulation. At present, the simulation software of industrial robots is mainly computer simulation and lacks realistic simulation software. The existing robot simulation software can only model the motion of the robot, but cannot accurately describe the positioning and Angle of the welding contact, nor can it model the arc flicker, melting and weld forming in welding, nor can it obtain the information of the robot's motion speed, current, voltage and Angle in real time, thus affecting the accurate evaluation of welding quality [3]. Therefore, a virtual reality welding robot simulation system for practical application is developed based on the training and application of welding robot for practical application, which has important theoretical and practical application value for promoting the development of industrial robots in China.

II. DESIGN OF WELDING ROBOT TEACHING RESOURCE SYSTEM BASED ON VIRTUAL SIMULATION

A. Architecture

After obtaining the corresponding numerical simulation, the virtual platform of welding robot will be programmed offline to match the design requirements, and input it into the welding workstation of KUKAC4 to realize the welding experiment of the corresponding welds in the pre-set environment. This method is feasible

and can combine theory with practice, which is more in line with the needs of enterprises and markets [4]. The basic function of the teaching resource demonstration system is to provide students with virtual welding resources of various processes, parameters and workpieces, so that students can better understand and master the materials. By giving each student a welding operation, the student can select various welding processes, weld structures, temperatures and welding processes on the teaching resource demonstration platform, and output the corresponding virtual simulation welding results, and then modify the previous selection until the most suitable welding process, weld structure, temperature and welding process is selected [5]. To successfully perform virtual welding. The teaching resource demonstration system can show the students a large number of welding scenes and virtual welding resources stored by the students in the way of practical operation. At the same time, it can also guide the students to have an accurate understanding of the welding-related theoretical knowledge said by the teachers in the classroom, so as to achieve the teaching purpose of integrating theory and practice.

1) The virtual simulation experiment platform of welding robot arm was established. The platform consists of two parts: one is software, the other is hardware. In terms of software, I chose Unity3D platform, which can generate VR environment, control industrial robots, and feedback situational information. The software is mainly composed of helmet, PC, virtual reality device, support platform, simulation welding gun and so on. 2) 3D modeling of industrial robots and their core components based on 3D models. An industrial robot model based on 3D Solid model is established by using Solid-WORKS finite element analysis tool. A new method based on robot joint motion simulation is proposed. The 1:1 simulation model of welding head, welding table and welding workpiece in the welding process is established. To solve the problem that documents generated by SolidWorks cannot be directly input into Unity3D, 3Dmax is adopted to optimize them and input them into Unity3D. 3) Implementation of human-machine dialogue interface. In addition, in order to meet the functional requirements, the human-machine interface is divided into network connection, human perspective, state transfer, working state of industrial robots, joint motion speed of industrial robots, operation control in the operation process of industrial robots, etc. 4) Integration with actual welding simulation training is realized. The 3D modeling of industrial robots, welding parts, etc., is 1:1 with the physical object, and can be rotated and scaled through the operation interface, which is convenient for users to observe the working condition of the robot from multiple perspectives [6]. The simulation system realizes real-time communication with welding simulation training platform. According to welding speed, welding current, welding voltage, welding Angle and other parameters. The simulation data of welding process is formed and the results are fed back to the virtual simulation system.

B. System Structure

the software is composed of four parts: adjustment device, control device, storage device and display device (Figure 1 is quoted in A detection and configuration method for welding completeness in the automotive body-in-white panel based on digital twin). Among them, the adjustment part includes welding state adjustment module, welding process module and other parameter adjustment module [7]. In the teaching resource demonstration system, the user can select various welding conditions, processes and other parameters in the adjustment module according to the requirements of the welding task, and input related control commands to the control device through the adjustment component. The control device will store the teaching resources in the memory device according to the control command. According to the specific set values of the process and other parameters, the synthetic virtual simulation flow and simulation results are simulated to the display device of the display device, and the simulated results are finally output, and the selected welding process is modified in real time according to the obtained results [8]. The most fundamental condition for establishing a digital twin model is the coincidence of "virtual and real". Firstly, the welding manipulator is calibrated, its DH parameters are obtained, and then its tool is calibrated. Finally, the three-point method is used to measure the attitude of the external equipment. The corresponding relationship is obtained by calibrating the parts and then imported into the twin-crystal model of the parts.

a) Adjusting device

Through the input of each module, the adjustment of the state of the weld is realized, and the adjusted state of the weld is transformed into a control command that can be identified by the control department, and the control command is transmitted to the control department, so as to realize the adjustment of the good weld process and weld effect in the subsequent teaching resource demonstration [9]. The core content of the welding working condition model is to select the welding structure, welding temperature and welding time, and realize the corresponding output of welding process and welding results by selecting the welding structure, welding temperature and welding time. With the change of welding structure, temperature and time, as well as the change

of welding process, the welding quality changes. Among them, the different welding processes are analyzed in detail. Through the selection of various methods, the actual welding procedures of various methods and corresponding practical welding results are shown to the students. The other parameters are the channel detection, parameter setting and so on.
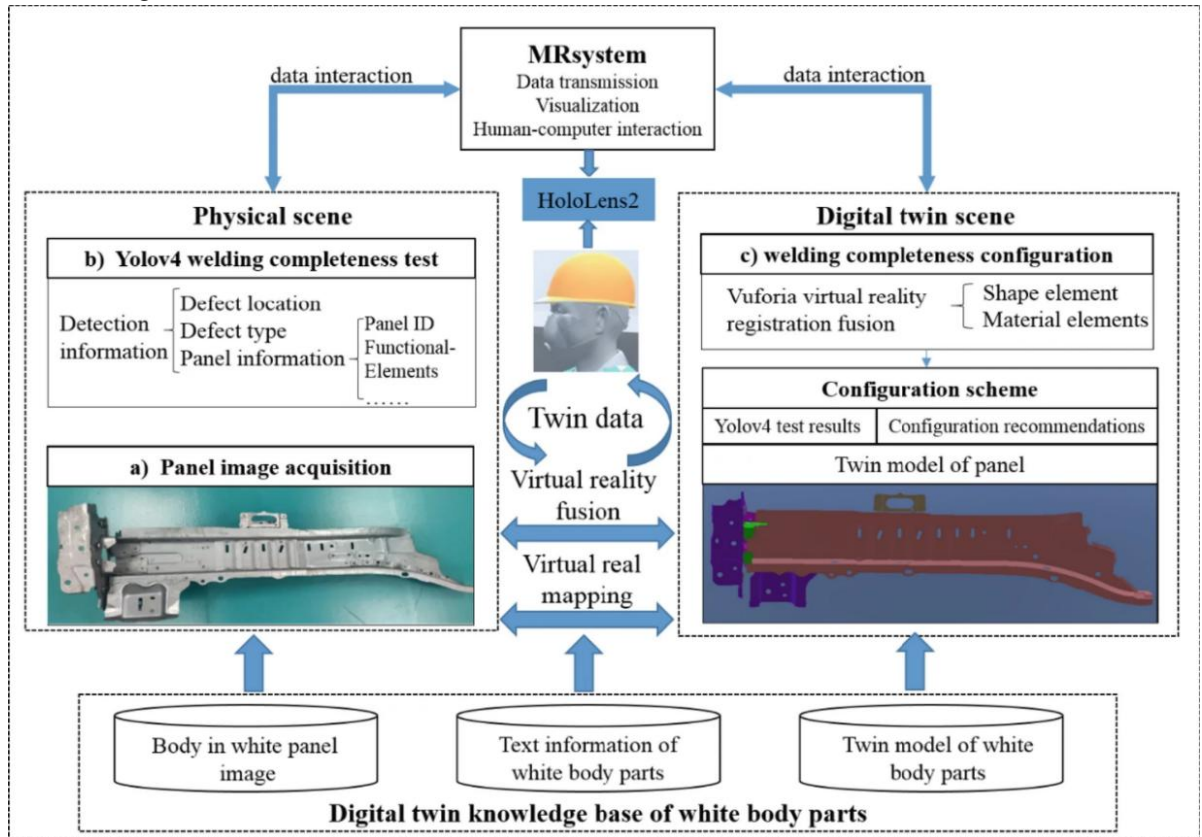

Fig.1 Structure diagram of virtual welding simulation system

b) Control Unit

As the core part of the system, it not only receives the adjustment command of the adjustment device, but also operates and displays it. According to the adjustment instructions received, some teaching resources stored in the memory are called, and the called teaching resources are dynamically compared [10]. After the comparison, a display command will be generated, and the dynamically matched teaching resources will be displayed completely in real time on the display of the terminal. After the virtual welding process is finished, the controller calculates and evaluates the virtual welding process, and obtains a virtual welding result.

c) Storage device

The invention relates to a database and an auxiliary component that can store teaching materials separately. Receive the call command from the controller, mark the corresponding teaching resources in the database according to the call instructions, and encapsulate the marked teaching resources into the controller after the marking is completed.

d) Display unit

It realizes the dynamic monitoring of the equipment, and realizes the real-time and comprehensive display of teaching resources. When receiving the display command of its own control department, the terminal display device will be opened, and the display screen of the terminal will also receive the dynamic teaching resources sent from the control department, and will be displayed on the display screen of the terminal [11]. At this time, a virtual welding process will appear on the screen, and when the virtual welding process is finished, the virtual welding process is received by the virtual welding process of the control component, and the virtual welding process is displayed on the display screen of the terminal.

III. DESIGN OF DIGITAL TWIN DATA PROCESSING ALGORITHM

A. Cooperative action control of positioner

a) Requirements

A new method based on the cooperative work of robot, positioner and workpiece is proposed, that is, to realize the long-term plane welding of space surface welds. In addition, the mass of the positioner is relatively large, the energy consumption is large in the handling process, and it will also cause certain interference to the smoothness of its operation, which has an adverse impact on the cooperative work of the robot and the workpiece. In actual work, it is necessary to ensure that the welding torch tip of the manipulator maintains a certain movement in a certain position, ensure the smooth welding seam [12]. Therefore, the path planning method used in this paper is to find out the optimal scheme of the platform, so that the required amount of movement is as little as possible, the relative movement between the robot and the object to be processed is as smooth as possible, and the welding point is within its accessible distance.

b)   Design of basic principles of algorithm

From the point of view of the amount of movement of the positioner and the smoothness of the relative movement of the robot and the workpiece, the method of plane welding must be used, so that it can be seen that the welding gun must be vertical. That is, the pose of the weld can be expressed as $(\alpha, \beta, \gamma, S\gamma, 0, 0)$. During the welding process, it is necessary to adjust the weld attitude of the welding workpiece [13]. It can be seen from Figure 2 that the adjustment of the welding position of the workpiece is to adjust the positioner (the picture is quoted in Robot path planning with two-axis positioner for non-ideal sphere-pipe joint welding) based on laser scanning). In order to ensure that the welding torch posture of the workpiece is always in a vertical position, the following equations can be listed:

$$\begin{pmatrix} \cos\varphi 1 & 0 & -\sin\varphi 1 & 0 \\ 0 & 1 & 0 & 0 \\ \sin\varphi 1 & 0 & \cos\varphi 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} \cos\varphi 2 & -\sin\varphi 2 & 0 & 0 \\ \sin\varphi 2 & \cos\varphi 2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$* \begin{pmatrix} s_{11} & s_{12} & s_{13} & s_x \\ s_{21} & s_{22} & s_{23} & s_y \\ s_{31} & s_{32} & s_{33} & s_z \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & 0 & \alpha \\ S_{21} & S_{22} & 0 & \beta \\ 0 & 0 & 1 & \gamma \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{1}$$
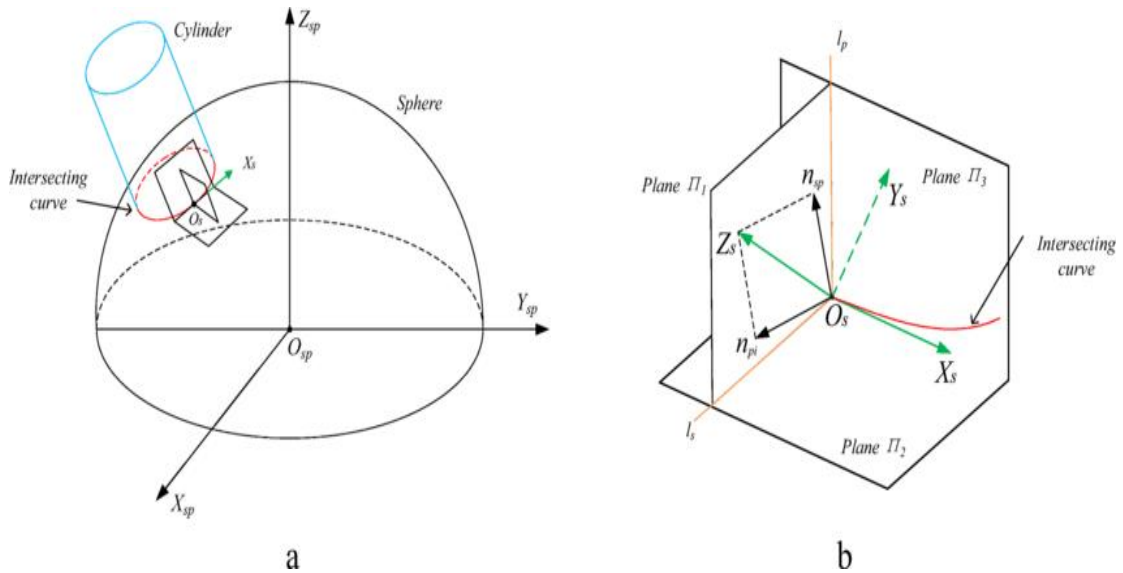

a   b

Fig.2 Coordinate system of welding workstation

$\varphi 1$ represents the Angle at which the positioner rotates around axis $\beta\varepsilon$, and $\varphi 2$ represents the Angle at which the positioner rotates around axis $\gamma\varepsilon$.

By simplifying the above formula (1), the following formula can be obtained:

$$s_{13} * \cos\varphi 1 * \cos\varphi 2 - s_{33} * \sin\varphi 1 - s_{23} * \cos\varphi 1 * \sin\varphi 2 = 0 \tag{2}$$

$$s_{23} * \cos\varphi 2 + s_{13} * \sin\varphi 2 = 0 \tag{3}$$

$$s_{31} * \cos\varphi1 + s_{11} * \cos\varphi2 * \sin\varphi1 - s_{21} * \sin\varphi1 * \sin\varphi2 = 0 \qquad (4)$$

$$s_{32} * \cos\varphi1 + s_{12} * \cos\varphi2 * \sin\varphi1 - s_{22} * \sin\varphi1 * \sin\varphi2 = 0 \qquad (5)$$

$$s_{33} * \cos\varphi1 + s_{13} * \cos\varphi2 * \sin\varphi1 - s_{23} * \sin\varphi1 * \sin\varphi2 = 1 \qquad (6)$$

The value of $\varphi2$ can be obtained by using the above formula (3), and then the value of θ1 can be obtained by substituating the calculated solutions into the matrix to the right of the above formula (1), and the position value of the weld, that is, (α, β, γ), represents the position value of the key point of the weld that meets the attitude requirements. Finally, the solution closest to the robot is selected as the optimal solution.

B. *Welding process knowledge base*

a) *Integration of welding cases*

To this end, the weld material, weld type, weld position and other similar characteristics of the weld are modeled, and the problems in the excessive database are optimized.

b) *Global registration*

Through the initial matching of the workpiece identified in the biphase structure of the welded part, the workpiece meeting the process requirements is selected. Secondly, the existing welding process parameters are refined, and the welding process parameters with the biggest deviation are selected.

c) *Special screening*

For cases that are automatically screened out, there may be cases where the process parameters are beyond the reach of existing welding equipment, so a range of screening can be performed by setting the maximum current, maximum voltage, maximum welding speed and maximum gas flow.

d) *Updating and perfecting process knowledge*

The quality of the weld is one of the main factors to measure the quality of the weld, and the spatter rate of the weld, the stability of the weld and the penetration performance are the three main factors to measure the quality of the weld [14]. Whenever a new product finds a similar old product, it is integrated and can also be directly increased, so as to achieve the continuous update and improvement of product knowledge.
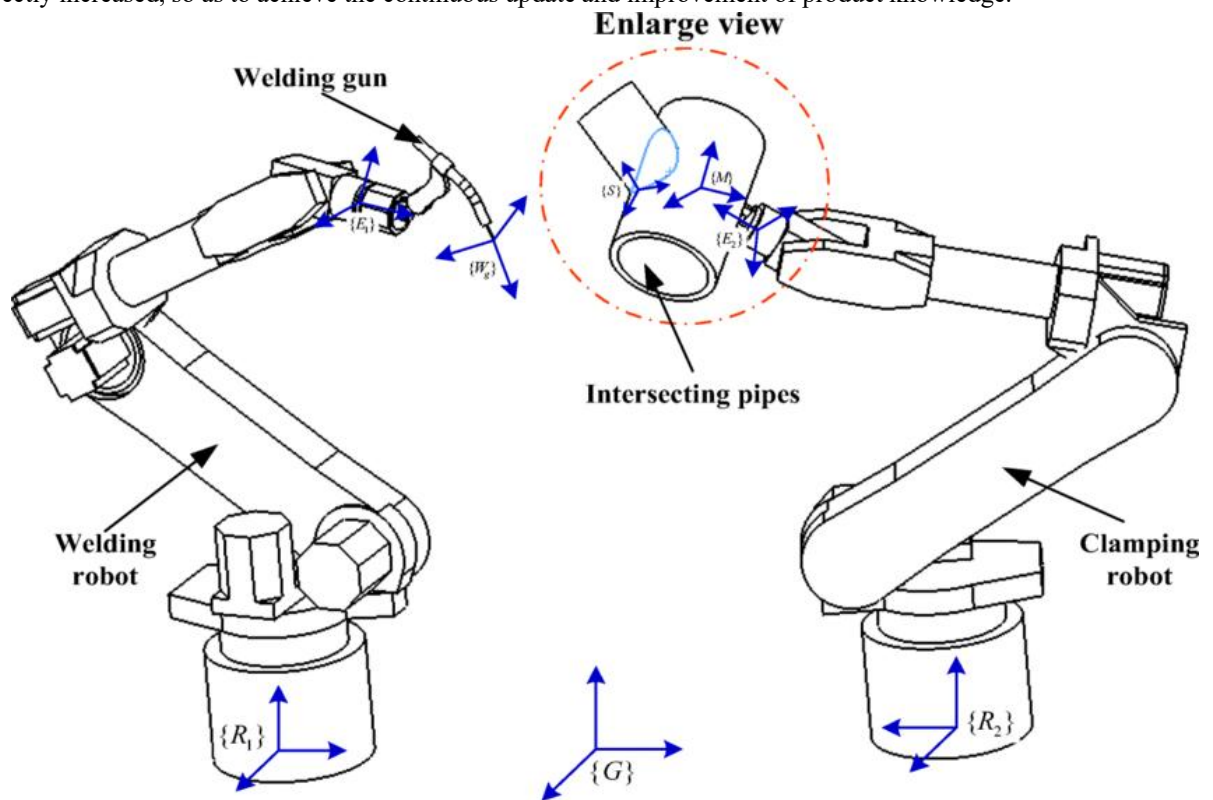

Fig.3 Welding workstation layout diagram

C. Digital Twin Function Service Layer

At the user-oriented business level, based on the twin sub-model and twin sub-data, differentiated services can be provided to users according to each stage of the product development process, so as to achieve the optimal decision [15]. In the welding process, the process parameters are visualized and integrated with historical data to realize real-time monitoring and optimization of the process.

a) VR Layout Design

The system is based on Unity, making it easy to design products that match virtual reality. The system uses VR controller to design a set of job site layout program. By wearing VR equipment, it can design the layout production line and arrange the welding station in the virtual workshop. Since the actual size is 1:1, the structure of the product can be seen and corrected more directly [16]. It is convenient for users to complete the production line layout plan better and faster (Figure 3 is quoted in the Simulation and Trajectory Generation of Dual-Robot Collaborative Welding for Intersecting Pipes).

b) Virtual weld operation simulation

The software has a real and intuitive welding process simulation function, which can not only accurately simulate the moving track in the welding process, but also simulate the welding effect and laser positioning effect. Through visual simulation, it is clear that the vehicle is moving without impact, and if there is an impact, the simulation warning will be highlighted and terminated (Figure 4 cited in Appl.Sci.2023, 13(10), 6082).
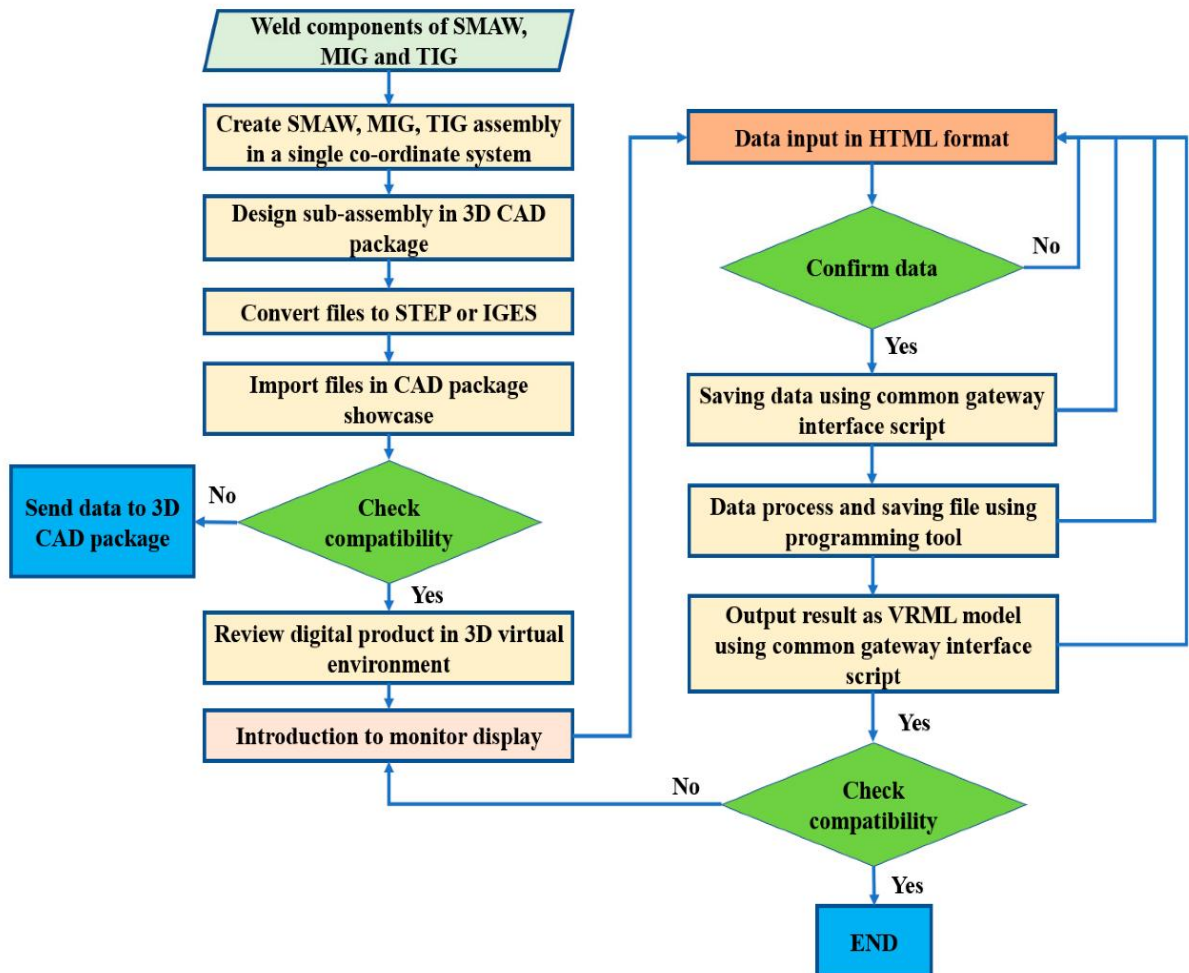

Fig.4 Simulation flow of visual operation of weld

D. Digital Twin Data Transfer Switching Layer

Different manufacturers of equipment in the access mode, data type analysis and format are different, which requires the industrial Internet to achieve the interconnection between devices. in order to solve the problem of multi-source heterogeneous data acquisition, the system adopts the Digital Twin data communication Network architecture based on OPCUA, as shown in Figure 5 (the picture is quoted in When Digital Twin Meets Network

Softwarization in the Industrial IoT: Real-Time Requirements Case Study). The data generated by the twin model simulation relies on the data transfer and exchange layer, which is uploaded to the "cloud" to support the operation of certain services.

This project takes KUKAC4 welding robot as the research object, and takes welding control, welding calculation and control variable calculation as the main means. The software designed the software database field key value, and completed the data model construction, using welding control, welding calculation, calculation control variables and other functions [17]. The system can provide users with the calculation formula of the method and size of welding engineering information, which is convenient for users to study and research. After the data is calculated, virtual operation can be carried out in the software.
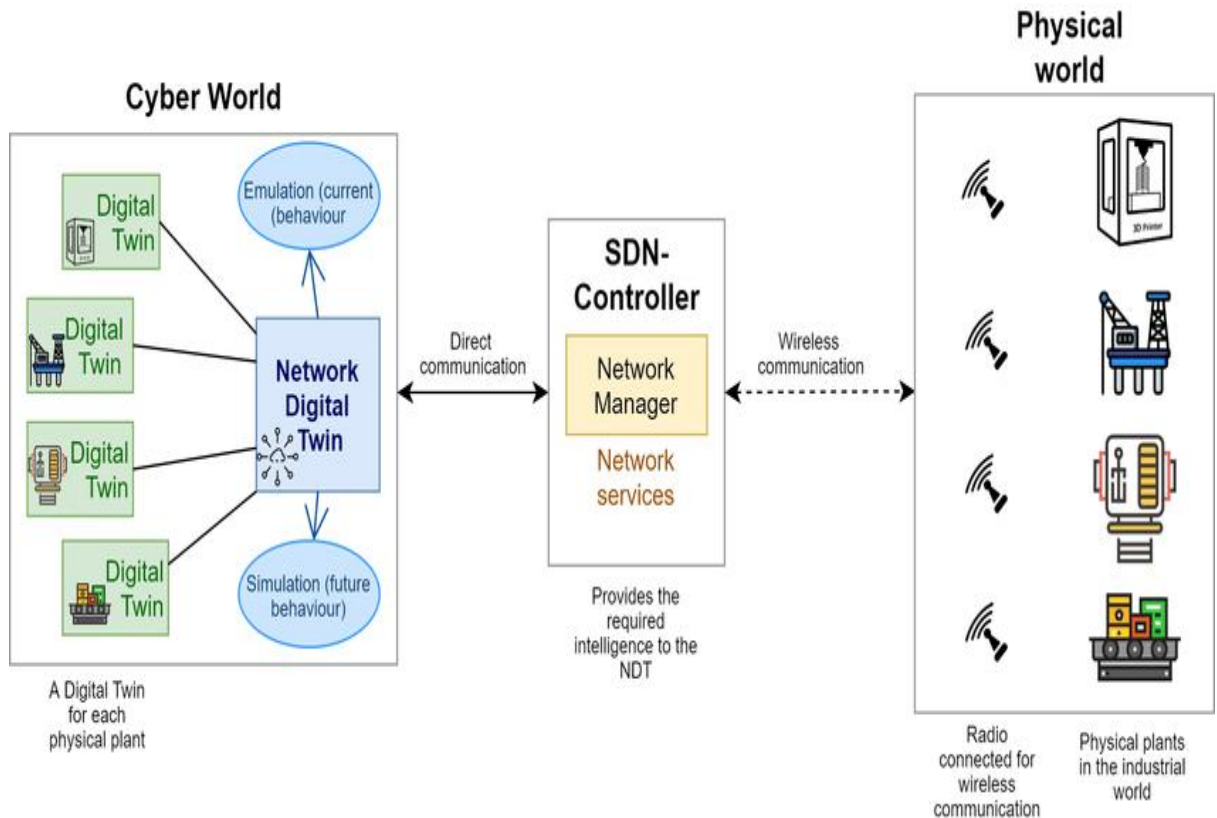

Fig.5 Digital twin data communication network architecture

IV. DEVELOPMENT OF DEMONSTRATIVE TEACHING RESOURCES

A. Building the Main Interface

By monitoring keys, various events can occur. The main interface of the control system realizes the setting of each module in the regulating device. According to the above functions, the corresponding keys are designed for users to input and output under various welding conditions.

B. Automatic adjustment of welds

Welding control interface refers to the welding structure of the welding device and its control of an operation interface, as long as you click the interface, you can directly access the corresponding functional interface, the interface contains a large number of functional modules and key information, the user can choose the corresponding welding structure and other related parameters to control, if selected, Then the terminal will output the corresponding virtual welding process and welding results. This Interface is shown in Figure 6 (the image is referenced from Yaskawa Motoman's Universal Weldcom Interface simplifies welding process control).

The welding operation interface in the welding process mainly includes the welding structure, welding symbol and welding algorithm, which is a control interface to adjust the welding state of the parts. The interface for the Welding mark is shown in Figure 7 (image cited in Creating a Welding Symbol). The welding mark interface is the combination and setting of the universal welding mark [18]. According to the welding technical drawing, the appropriate welding mark is selected, and the selected welding mark is automatically identified by the system and the corresponding operation is carried out.
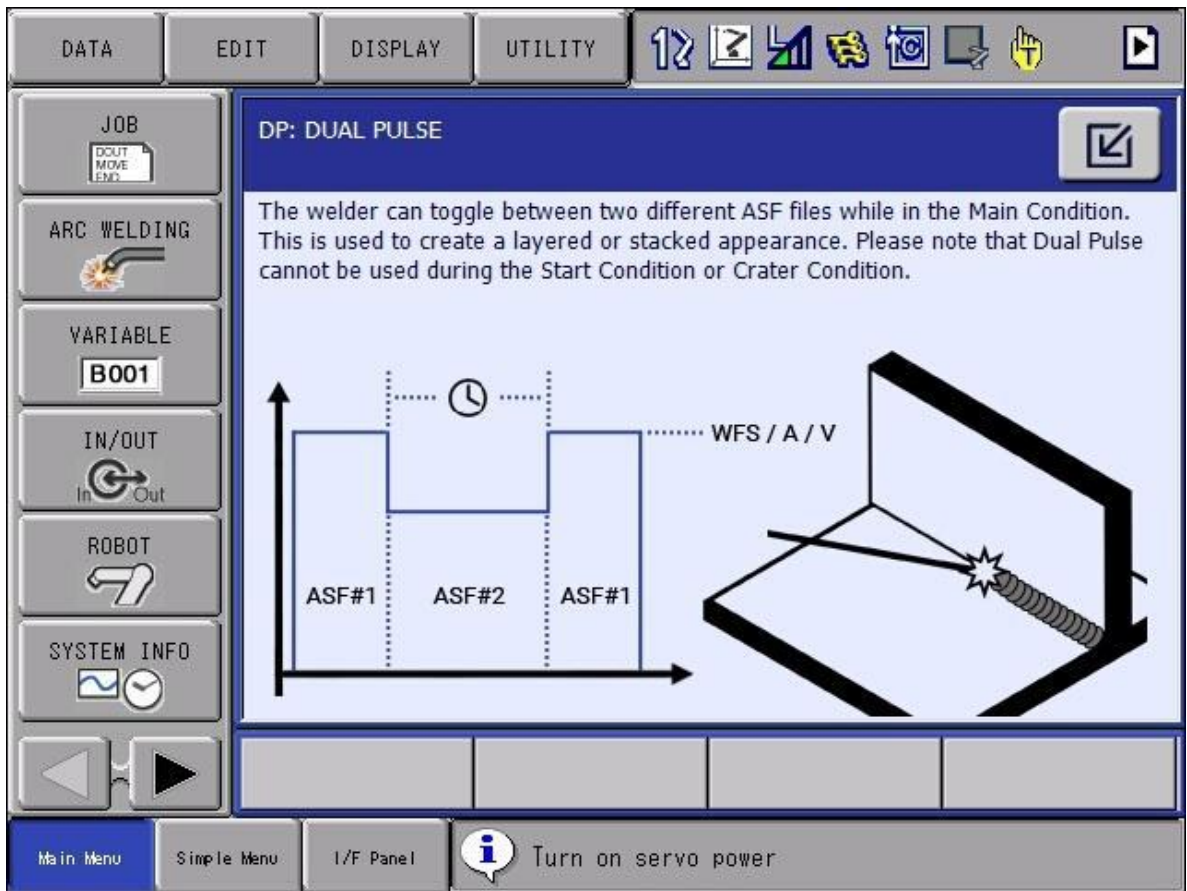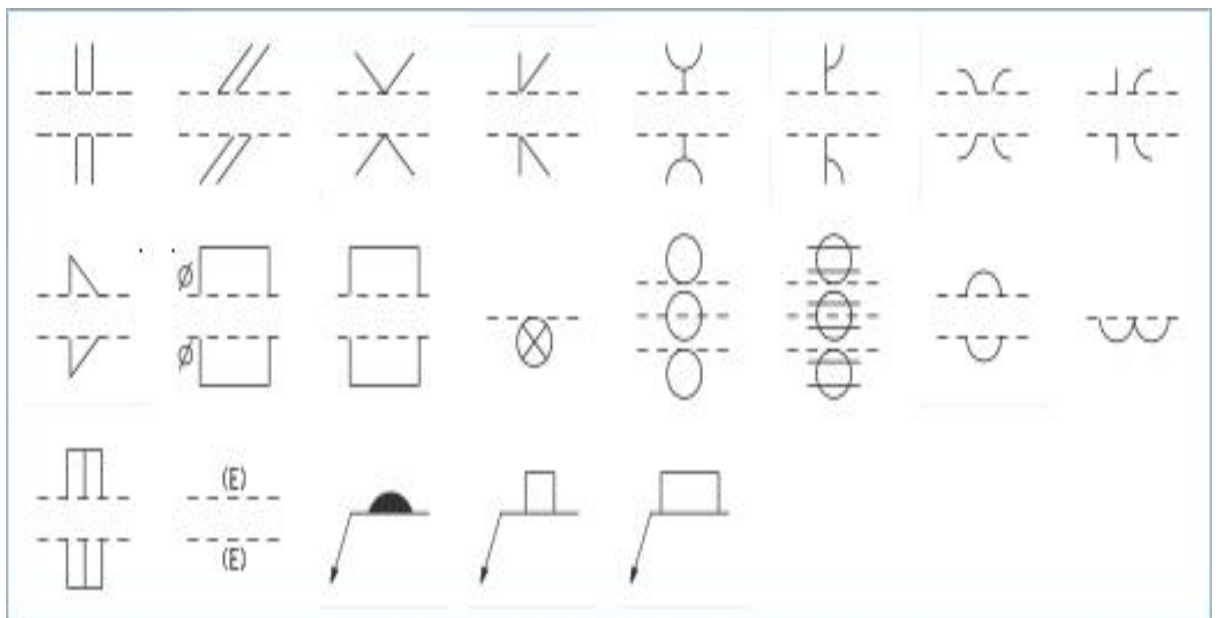
Fig.6 Welding control interface

Fig.7 Welding symbol interface

C. *Weld coating*

The function of the welding temperature control interface is to specifically set the temperature parameters of the welding device during welding [19]. When the welding temperature design command is activated, it will be transmitted to the corresponding functional interface, which contains a large number of functional keys and parameters. Users can choose the appropriate welding temperature according to their own welding work, thus achieving a virtual welding process. And the corresponding welding results are output. This interface is shown in

Figure 8. Three modules are designed: maximum rise slope module, interval slope module and set temperature module. (1) The maximum slope model is a comprehensive numerical simulation of the maximum slope of the warming rate, including a variety of parameters, which can be set by the user. (2) The interval slope board, that is, the interval slope quantity in the heating process is a comprehensive numerical calculation, which contains a variety of parameters, which can be set by the user. (3) Setting the temperature control board is to set the specific setting of temperature rise parameters, which contains a variety of parameters for users to set themselves.

The channel detection interface realizes the setting of specific parameters of weld detection. The function of the interface is to realize the detection of each parameter through the interface, and combine the feedback value with the target value, and determine the start of the control command according to the set parameters, so as to carry out virtual operations according to the control channel [20]. Channel detection interface mainly includes channel information, channel setting, channel calculation and channel orientation.

The parameter setting interface focuses on the basic parameters of the specific welding device. The welding parameters here are basically composed of all the welding parameters in the common welding method. Users can select the corresponding welding parameters according to their own welding work and set them [21]. The virtual welding process and the virtual welding result are output in real time, and the relevant process parameters are adjusted according to the results, so as to realize the process control.
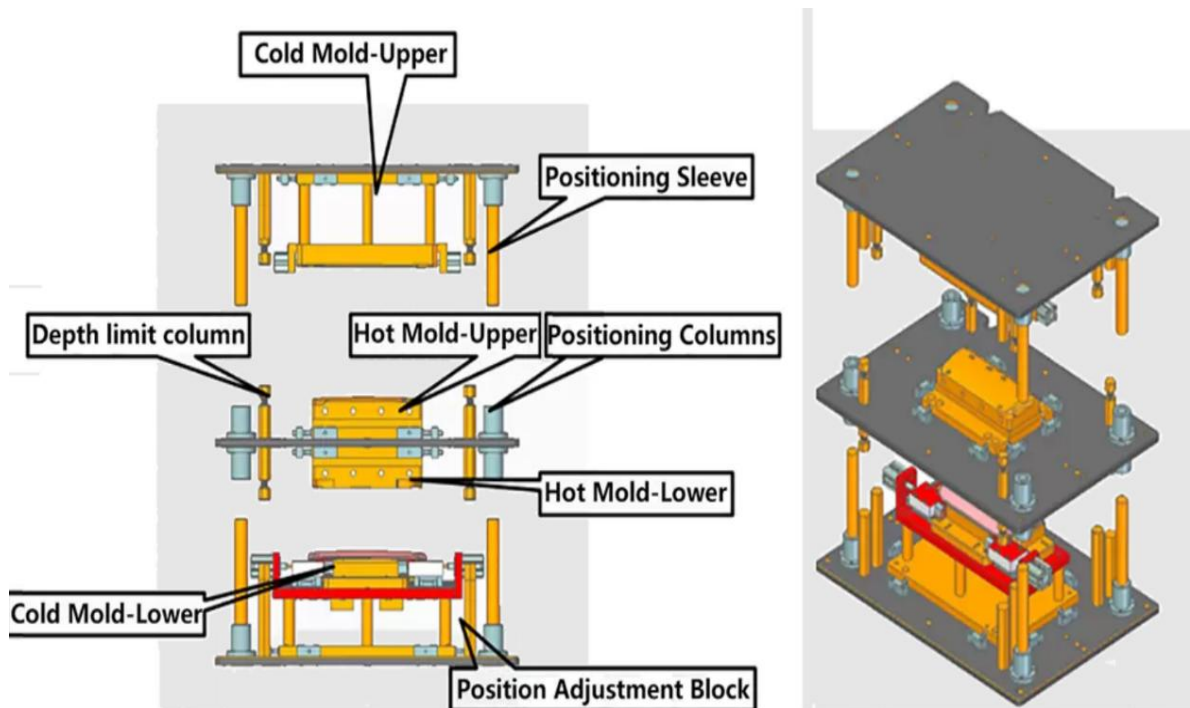

Fig.8 Welding temperature control interface

V. VIRTUAL SIMULATION AND RESULTS DISPLAY

A. Using Virtual Simulation

When the operator uses the software, the software simulates various sensors in the welding handle through VR, the system will obtain the position and pose of the welding machine, and realize the dynamic simulation of the welding torch and weld in the software (Figure 9).

In the simulation system, parameters such as welding current, voltage, welding speed, and protectors can be manually set. At the same time, when welding, the VR welding gun should be moved to a specific location to collect welding data in real time. The simulation software will convert these data into virtual data for analysis and processing. Specific welding data is generated on the screen (Table 1).
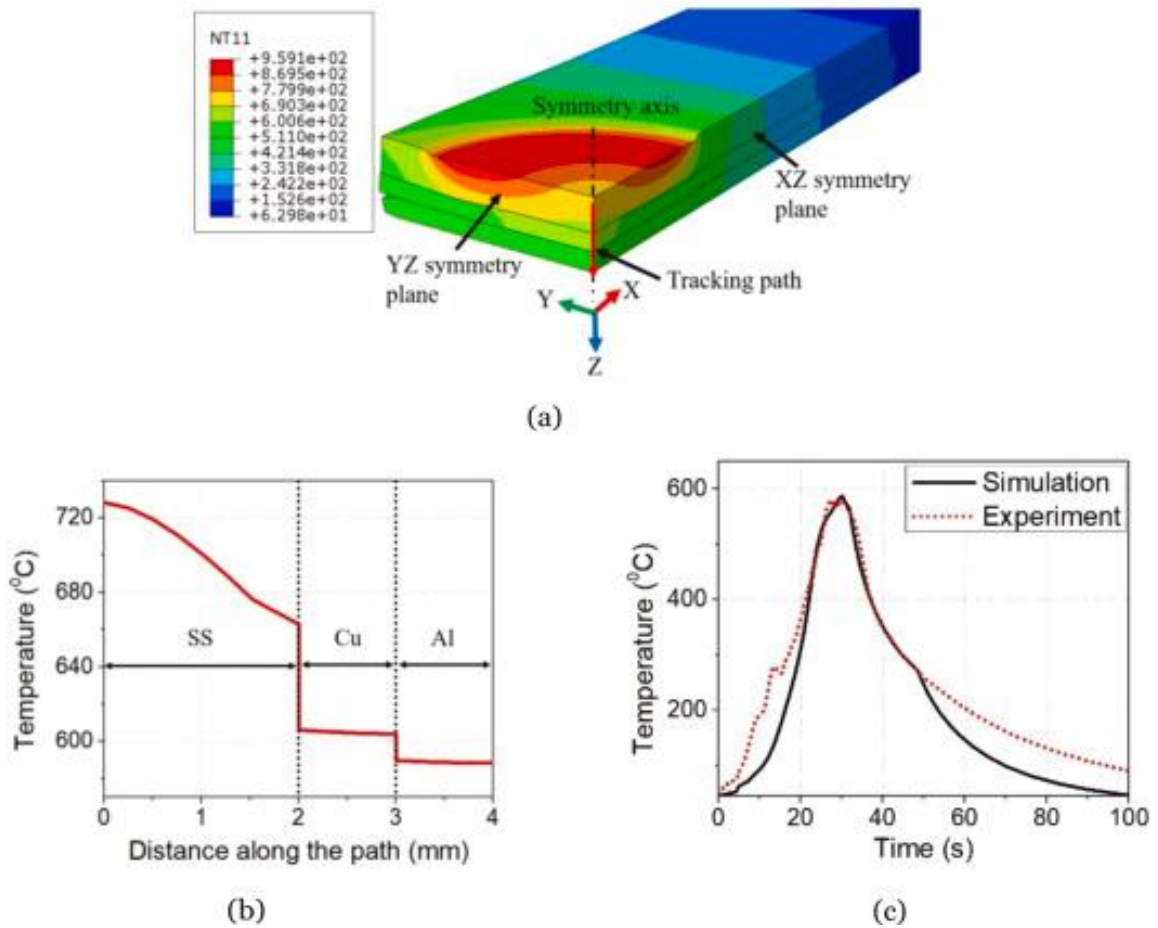
(a)

(b)

(c)

Fig.9 Welding and welding simulation

Table 1: Data generated by virtual simulation software

method	Filler	Welding speed v(/mm/min)	Gas	Swing arc mode	Weld width W/mm
weld	ER70S-6	500	Helium and carbon dioxide	Straight line	6.47
weld	ER70S-6	800	Helium and carbon dioxide	Straight line	5.56
weld	ER70S-6	1100	Helium and carbon dioxide	Straight line	5.11
weld	ER70S-6	1400	Helium and carbon dioxide	Straight line	4.54
weld	ER70S-6	1700	Helium and carbon dioxide	Straight line	4.01
weld	ER70S-6	2000	Helium and carbon dioxide	Straight line	3.71

B. *Display of welds in real scenes*

The actual ABB1400 automatic welding workstation was used to set welding current, voltage, speed, protective gas and other related parameters, and compared with the virtual simulation software. The process parameters of welding manipulator were tested. Table 2 shows the welding parameters of the welding robot. With the increase of power, the heat line per unit distance increases continuously. And over time, the width of the weld is also increasing.

Table 2: Actual welding data of welding robot

method	Filler	Welding speed v(/mm/min)	Gas	Swing arc mode	Weld width W/mm
weld	ER70S-6	500	Helium and carbon dioxide	Straight line	6.45

weld	ER70S-6	800	Helium and carbon dioxide	Straight line	5.54
weld	ER70S-6	1100	Helium and carbon dioxide	Straight line	5.01
weld	ER70S-6	1400	Helium and carbon dioxide	Straight line	4.50
weld	ER70S-6	1700	Helium and carbon dioxide	Straight line	3.97
weld	ER70S-6	2000	Helium and carbon dioxide	Straight line	3.67

VI. CONCLUSION

Virtual simulation training has been widely used, which is a main part of the training course and an effective method. The virtual simulation teaching method, which focuses on cultivating students' ability, is perceptual, interactive and innovative. The teaching resource demonstration system is carried out on the virtual simulation platform of welding robot, and its core is to demonstrate virtual welding resources of various processes, parameters and workpieces to students, so that students can have a clearer understanding of welding technology and process requirements. This has certain guiding significance for the practice and employment in application-oriented colleges.

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