Research on Key Technology of Safety Measure Control in Substation Large Overhaul Site

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Abstract—A key technical solution for safety control of large-scale maintenance site measures in open substations is proposed. Firstly, the semantic analysis technology framework of the safety measures scheme is constructed. Natural language processing technology is applied for recognition. A novel Multi-TFC network model is proposed, which can simultaneously complete three sub-tasks of work ticket classification, frame extraction and text detection, and realize automatic generation of substation work tickets to safety measures steps. At the same time, it adopts real-world modeling technology for overall 3D modeling of substations, integrates the deep learning model for the above-mentioned work ticket to safety measures program generation, develops subsystems and display interfaces for work ticket and safety measures step generation of the safety measures control platform, receives intelligent analysis and calculation results of safety measures based on the transmission of the safety measures control platform, and establishes a location mapping database model of actual spatial coordinate positions and twin 3D scenes, and automatically generates 3D fences and security measures through The basic data automatically generates 3D fence and grounding line. Finally, it realizes the intelligent visualization presentation of the safety measures layout map.

Keywords-Substation robot; Text recognition; Control platform; Motion control

1 INTRODUCTION

There are many potential safety hazards in the traditional safety measures. Based on the current research situation at home and abroad, there are many researches on line patrol robots in the substation environment at home and abroad, and the technology is relatively mature. However, there are few researches on the ground wire hanging robots in the implementation of on-site safety measures in open substations, and there are few corresponding research results [1].

At present, the industry lacks a set of digital management platform specifically for safety measures management and control, and it is also unable to seamlessly connect with existing auxiliary control platforms, so as to achieve efficient and standardized management of the whole process of on-site safety measures management and control [2]. Therefore, this project has carried out the research on the intelligent safety measure management and control platform, and it has become a realistic demand to carry out the research and application of the key technology

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of safety measure management and control on the large maintenance site of the open type substation [3].

2 ELATED ALGORITHM TECHNOLOGIES

Combined with the normative description of security events, and based on the statistics and analysis of the characteristics of a large number of work tickets, the internal rules and regulations of security measures are summarized and extracted, and the matching rule base and database of typical work tickets are constructed. A set of research on key technologies of field security measures to assist the execution is designed. The main contents are as follows.

2.1 The state estimation technology of the Ancuo operational auxiliary robot

Ancuo robot is mainly composed of cloud platform, master control, motion control, wire identification, lift, manipulator and electric ground rod [4]. The system composition of Ancuo robot is shown in Figure 1. Through wireless encryption and 4G communication technology, the real-time status monitoring between the Ancuo robot and the cloud platform is realized.

Intelligent sensing and monitoring technology is integrated to realize the state acquisition of robot chassis running and battery based on CAN open protocol, the position state estimation of lifting motor based on displacement encoder, and the position state estimation of manipulator based on contact and collision switch and pulse data [5]. After the above parts are designed and assembled, the robot contraction and expansion diagram is shown in Figure 2.

2.2Text recognition technology

Aiming at the existing work tickets in different power outage modes, the relevant image text deep learning algorithm model is adopted to train based on the existing work ticket data, and the automatic recognition of work ticket text is realized.

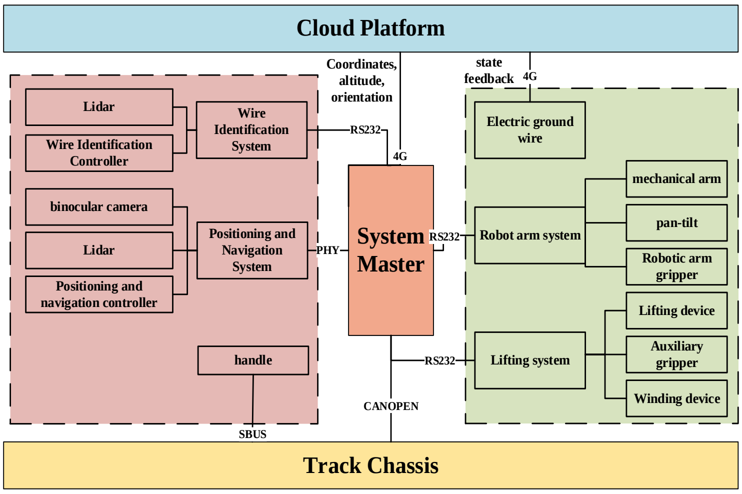

Figure 1. Robot System Block Diagram.

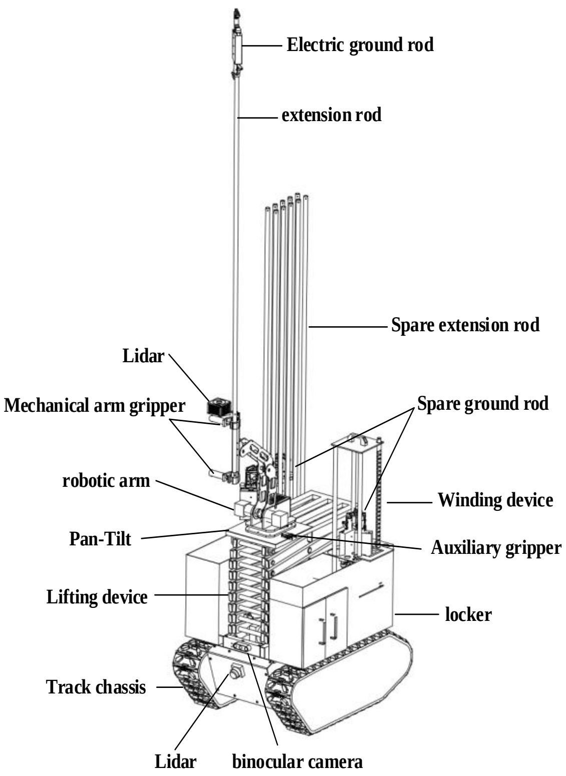

Figure 2. Robot structure diagram.

2.3 Motion control technology of manipulator

Intelligent bionic 6-DOF safe manipulator is the core of the whole robot. Connecting the ground rod by extending or contracting the arm is the most important part when the robot is working [6]. In this part, the motion state of the manipulator is analyzed first, and then the active disturbance rejection control technology is introduced. The active disturbance rejection control technology is used to control the manipulator, which improves the system control ability and robustness of the manipulator, and realizes the intelligent compliance control of the manipulator.

2.4 Platform control technology

As the human-computer interaction interface of the robot, the platform cloud platform is responsible for the instruction delivery and status information feedback. The cloud platform sends the coordinates, height and orientation information of the wires to be connected to the ground wire to the robot through 4G to guide the robot's work [7]. At the same time, the real-time picture, location information and working status of the robot are fed back to the cloud platform to complete the supervision of the robot by the platform.

3 SUBSTATION WORK TICKET IDENTIFICATION AND EXTRACTION ALGORITHM

At present, the information of substation work ticket cannot be synchronized with the maintenance site, so it is difficult to manage the maintenance site effectively in real time through the text information of work ticket. Therefore, this project takes the work tickets of the State Grid Yangzhou Power Supply Company as the object, and makes the intelligent identification system of typical work tickets for different power outage sites. A Multi-task network for text detection (frame extraction and classification) structure is proposed. To analyze and classify existing security solutions, deep learning and other technologies are used to establish multi-model analysis of work ticket text, effectively extract and process key information, and realize automatic generation of highly reliable security solutions. Finally, the identification and verification of the operation ticket of the transformer system of the AC 220kV Guangling substation of Yangzhou power grid prove the effectiveness of the system in the field implementation of the substation.

3.1 Multi-TFC interface location and text detection

In the interface perception module of the substation work ticket recognition system, a multi-task localization network Multi-TFC is proposed to combine the two tasks of text detection and interface localization into one network. Deep learning based text detection is based on extracting image features by deep convolutional neural networks and finding the location of text on images containing text. Due to the particularity of text sequences, the text detection algorithm has been improved on the basis of target detection. CRAFT (Character Region Awareness for Text Detection) is a commonly used text detection network [8].

Multi-TFC can simultaneously locate the interface position and detect the text on the interface. The network has two output branches. The first one is the semantic segmentation map of the interface and the background. The location of the interface can be found in the background by judging the connected domain. The second branch is the heat map of the character center and the character connection relationship. The image is first downsampled with a deep convolutional network, and a total of 5 downsampling is performed [9]. Then, the down-sampled feature map is stitched with the feature map of the previous layer and then up-sampled. The number of channels of the feature map obtained at this time is the same as the number of channels in the first layer of the down-sampling part.

3.2 Text recognition design based on multi-model network

For the recognition of text sequences, this paper uses an end-to-end text recognition network based on CRNN+CTC. This network has no limitation on the length of text sequences. It can recognize text sequences of uncertain length, which fits the needs very well. The overall structure of CRNN+CTC is shown in Figure 4, including convolutional layer, recurrent layer and transcription layer. In the convolutional layer, a VGG16 deep convolutional network is used as the backbone network to extract pixel space features from the input text sequence images. The size of the obtained feature map is stretched to form a feature sequence and input to the recurrent layer. The recurrent layer mainly consists of Bi-LSTM, a bi-directional long and short-term memory network, to extract the sequence features of the feature sequence [10]. The recurrent layer is followed by a fully connected layer, and then the softmax layer outputs the label distribution of the character categories contained in the images. The label distribution is the sequence represented by the category ordinal number. Finally, the CTC algorithm in the transcription layer is used to decode the category sequence numbers into characters and the final prediction is obtained by de-integrating and sorting the characters. Then, the loss between the predicted and labeled sequences is calculated and used to update the weights for back propagation in the network.

3.3 Work ticket classification extraction

Interface classification can determine whether the order of the interface displayed during the current operation is correct, and this step has a great impact on recognition efficiency and accuracy. In this section, a deep learning-based work ticket classification method is used to assist in classifying interfaces with similar text line structure and misclassification using a method based on text recognition results. Then a key information extraction algorithm based on template structure matching is used to mark each text box as a different category according to the key information. Finally, the interface of the form is corrected according to the status of the form recognition, and the recognition effect before and after the correction is compared [11].

3.4 Substation work ticket identification system

This section designs a system for automatic generation of safety measures operation steps from a typical work ticket of a substation to a work ticket of the AC 220kV Guangling substation system of Yangzhou power grid. The general rules for the automatic generation of safety measures operation steps of substation work tickets are also developed. The system is divided into three parts: character detection, character recognition and key information extraction. Figure 3 shows the system architecture for automatic generation of operational steps of safety measures for substation work tickets. The substation work ticket identification system can better meet the needs of daily management of work tickets and effectively improve the line operation and maintenance efficiency of intelligent substations, which is of positive significance to ensure the safe and stable operation of the power grid.

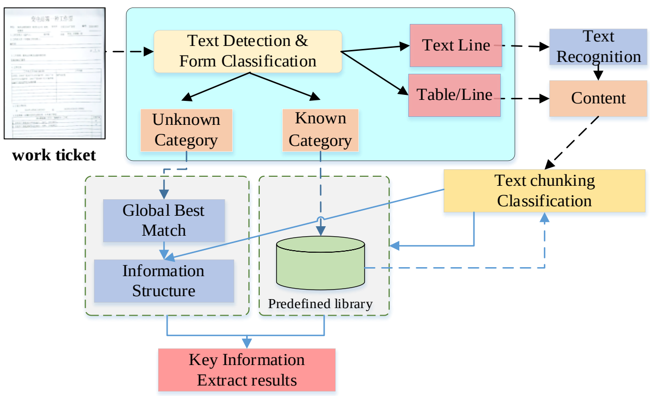

Figure 3. Structure diagram of substation work ticket identification system.

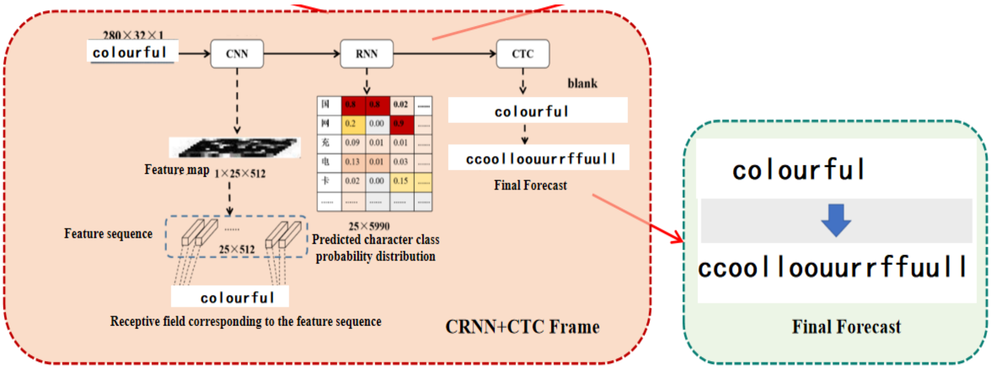

Figure 4. CRNN+CTC structure (Take the example of identifying "colourful").

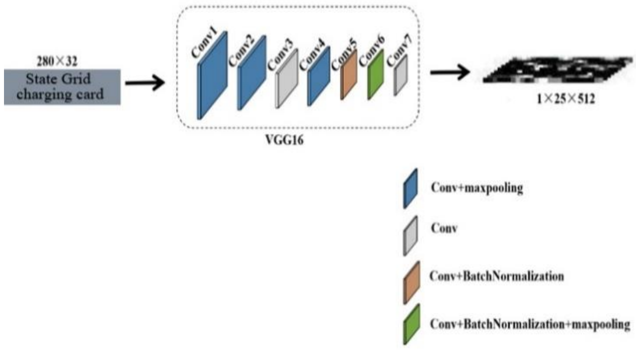

Figure 5. Convolutional layer structure based on VGG16

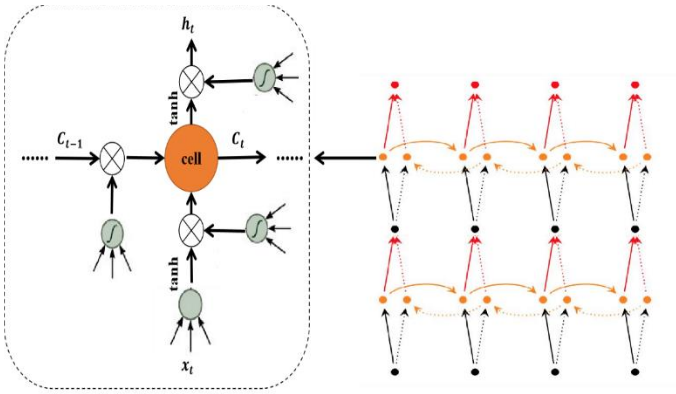

Figure 6. Network structure of Bi-LSTM

In this section, 12140 test images containing various tilt angles as well as light conditions were collected to carry out system testing, as shown in Figure 7. For the actual needs of the information processing module such as work ticket classification, text recognition, key information extraction, and operation button positioning. The recognition effects of VGG-16-based and Resnet-34-based were tested in comparison. The accuracy rate of human-machine operation work ticket classification and comparison experiments are shown in Table 1, and the accuracy rate of the Resnet-34 algorithm reaches more than 92% in the case of light and tilt angle changes.

Figure 7. Work ticket scanning process.

Table 1 Classification accuracy rate of HM operation

Classification methods	**Classification accuracy rate**	**Reasoning speed (s)**
VGG-16	91.9%	0.04
Resnet-34	92.7%	0.05

4 STUDY ON MOTION CONTROL OF INTELLIGENT BIONIC SIX-DEGREE FREE AND SAFE MANIPULATOR

Intelligent bionic six-degree free safe operation manipulator is the core of the whole robot. When the robot is working, it is the most important part to connect the ground rod by stretching or contracting the robot arm. In this part, firstly, the motion state of the manipulator is analyzed, and then the active disturbance rejection control technology is introduced. The active disturbance rejection control technology is used to control the manipulator, improve the system control and robustness of the manipulator, so as to realize the intelligent and compliant control of the manipulator.

4.1 Motion control of free and safe operating manipulator

Firstly, the forward and inverse kinematics model of the manipulator was analyzed. According to the distance between the wire and the ground rod to be connected, the relative initial position motion distance between the X-axis and the Z-axis of the manipulator was obtained. Since the ground rod is fixed at the end of the manipulator, the gripping mechanism at the end of the manipulator can maintain the same attitude, so the manipulator only needs to move to the target position. By studying the inverse kinematics of the manipulator, the motion angles of the X-axis and Z-axis stepper motors can be calculated.

Consider the kinematics parameters of the bionic machine system is established, and the mechanical arm automatic dismantling grounding line operation under the conditions of interference, establish a nonlinear dynamic model of mechanical arm, the L1 adaptive controller algorithm, the proposed algorithm not only can realize the state of the system input and output consistent transient performance, and is not dependent on the information system model [12]. Compared with the traditional adaptive control, the L1 adaptive controller can achieve the decoupling between the adaptive law updating and robustness, and can achieve a reasonable trade-off between the control performance and robustness more easily by choosing the bandwidth of the low-pass filter in the controller[7]. Therefore, this special control structure will be very suitable for the design of the controller of the nonlinear system with model parameter uncertainty and external disturbance, such as the automatic grounding wire hanging of the Anchor robot manipulator, so as to realize the intelligent and compliant control of the manipulator [13].

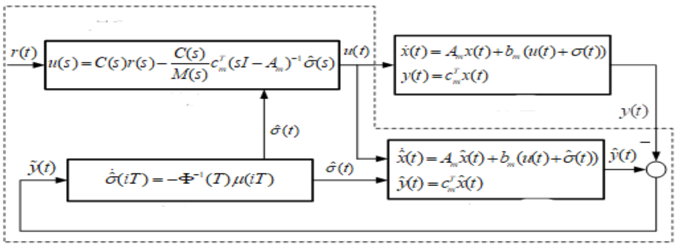

Figure 8. Structure diagram of closed-loop system of L1 adaptive output feedback control.

4.2 Active disturbance rejection control technique

The core of ADRC technology is to use an appropriate method to estimate the action of the system in real time by the difference between the actual output of the system and the expected output signal through the control input quantity, and make compensation in real time, so as to achieve the purpose of control. Active disturbance rejection is mainly composed of the following four aspects：

4.2.1 Arrange the transition process

In practical control systems, hope the system output $y\ (t)$ as soon as possible and no overshoot to track the input signal $v\ (t)$, the previous mentioned, classic PID control closed loop system of "quickness" and "overshoot" between contradiction, therefore in the system capability to withstand range, by prior arrangement transition process [14], to achieve fast and tracking without overshoot, At the same time, the differential signal is obtained. The specific algorithm is as follows.

With the set value $v(0)$ as the input, the tracking differentiator (TD) is used to arrange the transition process, and the discretization form is as follows:

$$\begin{cases} v_1(k+1) = v_1(k) + hv_2(k) \\ v_2(k+1) = v_2(k) + hfh \\ fh = fhan[v_1(k) - v_0, v_2(k), r, h_0] \end{cases} \tag{1}$$

Where, h is the sampling step; $fhan(\cdot)$ is the speediest control synthesis function, and its algorithm formula is as follows:

$$\begin{cases} d = rh_0 \\ d_0 = h_0 d \\ y = v_1 - v + h_0 v_2 \\ a_0 = \sqrt{d^2 + 8r|y|} \\ a = \begin{cases} v_2 + \frac{a_0 - d}{2} sign(y), |y| > d_0 \\ v_2 + \frac{y}{h_0}, \quad |y| \leqq d_0 \end{cases} \\ fhan = -\begin{cases} rsign(a), |a| > d \\ r\frac{a}{d}, \quad |a| \leqq d \end{cases} \end{cases} \tag{2}$$

Where, v_0 is the input signal; v_1 is the tracking signal of v_0; v_2 converges to the derivative of v_1; r is the speed factor. The larger r is, the faster the tracking speed is. h_0 is the filtering silver. The larger $h_0$is, the better the filtering effect will be, but it will bring a certain phase delay.

4.2.2Extended state observer

The purpose of designing expansive observation is to obtain the estimators z_1 and z_2 of variables v_1 and v_2 in the equation through the input and output of the system, and to estimate the synthesis of all internal and external disturbances acting on the system. The specific form is as follows:

$$\begin{cases} e = z_1 - y, fe = fal(e, 0.5, \delta), fe_1 = fal\ (e, 0.25, \delta) \\ z_1 = z_1 + h(z_2 - \beta_{01} e) \\ z_2 = z_2 + h(z_3 - \beta_{02} fe + b_0 \mu) \\ z_3 = z_3 + h(-\beta_{03} fe_1) \end{cases} \tag{3}$$

Where, b_0 is the approximate estimate of b; β_{01}, β_{02}, β_{03}; The specific form of $fal(e, \alpha, \delta)$ is as follows:

$$fal(e, \alpha, \delta) = \begin{cases} \frac{e}{\delta^{\alpha - 1}}, \quad |e| \leqq \delta \\ |e|^\alpha sign(e), |x| > \delta \end{cases} \tag{4}$$

Nonlinear characteristic $fal(\cdot)$ A very important feature is the "non-smooth" property. The efficiency of the non-smooth feedback is far better than that of the smooth feedback, both in terms of the steady-state error of the closed-loop system and the dynamic process of error decay. In terms of disturbance suppression, the efficiency of the non-smooth feedback is far higher than that of the smooth feedback in the nonlinear feedback.

4.2.3 Extended state observer

The specific form of the state error feedback rate μ_0 is as follows:

$$\begin{cases} e_1 = v_1 - z_1, e_2 = v_2 - z_2 \\ \mu_0 = k(e_1, e_2, p) \end{cases} \tag{5}$$

Where, p is a set of parameters; $\mu_0 = k(\cdot)$ is a nonlinear combination of different error quantities.

4.2.4 Disturbance compensation

The original integral feedback term is replaced by the total disturbance term z_3 which can be eliminated.

Since the immunity control technology to inherit and carry forward the classical control theory's thought essence, and also absorbed the achievements of modern control theory, based on modern microprocessor, digital technology, has realized the higher efficiency of signal extraction and processing, fundamentally improve the efficiency of "based on the error to eliminate the error", overcome the limitations of PID technology [14].

5 DEEP LEARNING-BASED SITE SAFETY MEASURES LAYOUT GENERATION

Based on the demand for digital substation modeling accuracy from the site Ancuo, the overall modeling of the substation is carried out using real-world modeling technology, and the study is based on low-cost physical modeling of the site's basic data, so as to form a physical location mapping table consistent with the actual spatial coordinate expression, and to realize the demand for high-precision positioning and location-related relationship of substation basic equipment.

5.1 Substation digital 3D modeling and positioning

The technicians use 3D laser scanning technology to scan the whole substation in all directions and quickly obtain the overall point cloud model of the substation. The point cloud data processing includes aligning, splicing, denoising and resampling of multi-site data. Then, according to different point cloud features, the three-dimensional spatial data model of the equipment is established; the three-dimensional model of the substation is mainly made by geometric modeling, and the geometric contour of the entity is extracted by segmenting the point cloud data [15], so as to carry out inverse modeling. Figure 9 shows the schematic diagram of the electric cloud data modeling.

Figure 9. Point cloud data modeling schematic.

The ground 3D modeling uses FARO X330 and other equipment to laser scan the substation equipment and facilities and buildings to collect 3D spatial location information and texture information of the object surface. The texture collected in the field is mapped onto the 3D model to form the model real texture. The texture mapping is shown in Figure 10.

At the same time to assist the use of geometric modeling method, based on substation pictures, design drawings and manufacturers equipment drawings, the use of AutoCAD and 3dMax, Maya and other professional software.to establish a three-dimensional model of various electrical equipment in the substation, and then set the model mapping and materials, stitching electrical equipment model to complete the substation three-dimensional field volume modeling. For example, the three-dimensional model of lightning arrester and its color map is shown in Figure 11.

Figure 10. Texture mapping schematic.

Figure 11. Lightning arrester 3D model comparison chart.

5.2 Visualization presentation of ATSO layout diagram

Based on the intelligent analysis and calculation results of the Ancuo layout map transmitted by the Ancuo control platform, the 3D fence and grounding wire are automatically generated through the basic data by combining the actual spatial coordinate position with the position mapping table of the twin 3D scene. At the same time, we study the size adaption of the fence in the twin space, the grounding wire hookup and the high-precision positioning of the grounding position.

Based on the information such as site collection photos and equipment drawings, a digital twin 3D scene model is created in equal scale with the actual scene objects, such as the twin 3D scene needed for the ATSO platform, the 3D fence, grounding wire, ATSO robot and electric grounding rod and other equipment needed in the ATSO layout plan. Then the realistic 3D design is analyzed and integrated with the Ancuo design plan through the study. Then the accuracy of the real-world 3D is determined according to the acceptable limit values of the process parameters. Finally, the Unity3D platform is used to simulate the actual Ancuo scene and dynamically generate 3D fences and grounding wires based on the basic data collected on site. Figure 12 and Figure 13 show the visualization interface of grounding wire hookup and the visualization interface of fence and signage respectively, while the interface shows the grounding wire hookup status and the high-precision positioning of grounding position according to the requirements of ATSO, so as to achieve the purpose of intelligent visualization presentation of ATSO layout map.

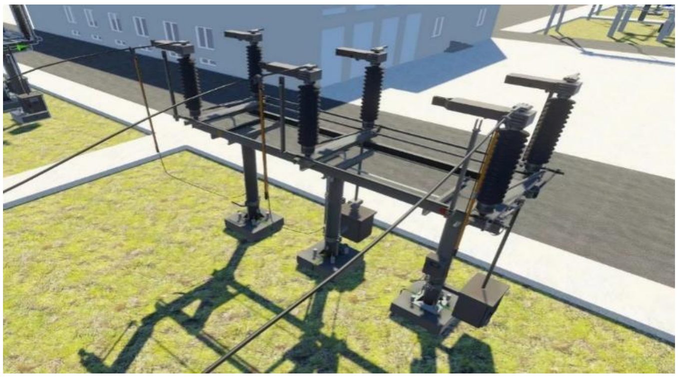

Figure 12. Visualization of the grounding wire hookup.

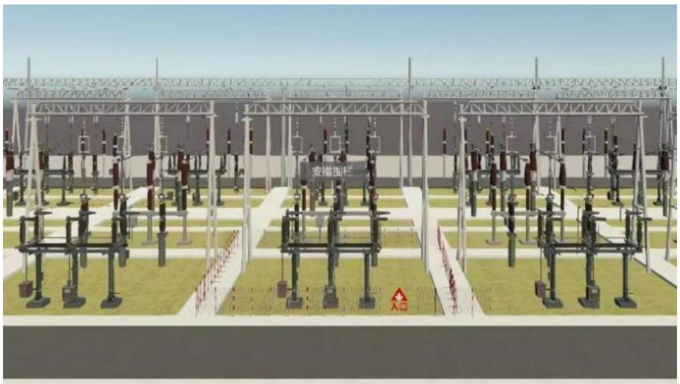

Figure 13. Visualization of the fence and signage hookup.

The technician establishes the substation equipment data management library according to the 3D model to realize the addition and modification of equipment data, etc. The graphic data display unit is used to show the specific data of the 3D model. The client user can access the intelligent 3D visualization platform of the substation's safety measures layout map through a browser or desktop software, etc.

6 SAFETY MEASURES MANAGEMENT PLATFORM

As the human-machine interface of the equipment, the substation safety measures platform can control and monitor the robot and grounding rod status in real time. The platform can improve the intelligence and less humanization of the safety measures control system. The main functions of the safety measures management platform are the following three aspects.

Intelligent generation of safety measures execution plan. It uses natural language processing technology to identify keywords such as voltage level, equipment type and work content in the work ticket. Automatically generate the safety measures implementation plan from the work ticket to the safety measures implementation plan.

Standardize the implementation of on-site safety measures layout. Establish the kinetics and kinematics model of intelligent robot to design intelligent safety measures operation robot. Combining with the safety measures layout diagram, the safety measures actions such as dismantling and connecting wires, arranging recycling fences and hanging signs are executed safely and standardized.

Comprehensive control of safety measures implementation status. Based on the model and data-driven safety state diagnosis and early warning algorithm, it realizes the all-round analysis and trend warning of safety measures control safety situation under complex operation scenarios. The information is synchronized to the platform in real time.

7 CONCLUSION

This paper designs a key technical solution for safety control of large-scale maintenance site measures in open substations, focusing on several key technical issues such as automatic recognition of work ticket images and texts, automatic generation of safety measures layout diagrams, safety measures robot design, identification and positioning of grounding point status, safety measures control platform, etc. It tackles artificial intelligence image and text recognition, mechatronics technology, automatic control technology, laser detection and identification technology, IOT monitoring technology, 3D modeling and visualization technology and integrated development of comprehensive software platform, etc., and carried out integrated innovation. Ancuo robot mainly consists of cloud platform, main control part, motion part, wire identification part, elevator, mechanical arm system part, and electric grounding rod. The Ancuo control platform integrates the automatic generation algorithm of Ancuo layout diagram, 3D visualization model, typical Ancuo scheme spatial location mapping database, Ancuo comprehensive process and status control, user management and other functions. At present, it has completed the development of work ticket scanning and identification, automatic generation of safety measures layout, safety measures process control, safety measures robot and electric grounding rod status monitoring and user management, etc. The platform has passed the laboratory environment interconnection and testing, and the relevant functions are normal, which can effectively realize the generation of existing work tickets to safety measures layout, and realize the remote control and status transmission of electric grounding rod status.

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