Design and application of visualized monitoring platform for substation equipment based on 3D modeling technology

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Abstract. With the rapid development of the smart grid, substation is gradually transforming to unattended monitoring mode, which puts forward higher requirements for the visualization of substation. At present, most of the visual display methods have some problems, such as non-intuitive, poor interactivity, high cost, etc. Based on this, this paper designs a visual platform for the status information of the substation equipment by combining the 3D realistic modeling and 3D software modeling technology on the basis of various modeling technology research. The platform can realize advanced functions such as real-time viewing of operation information, perspective analysis of equipment defects, and roaming inspection. Staff can quickly and accurately understand the status of the equipment, and improve the level of integration and intelligence of substation information system.

1. Introduction

With the rapid development of the power industry, the construction of high-voltage, ultra-high-voltage and grid automation applications is accelerating, and the process of smart grids has also entered a new era. Intelligent construction of substations is one of the most important and basic links to achieve smart grids [1]. At present, the substation is gradually changing to the unattended centralized monitoring mode. The traditional display mode based on graphics, tables, plane diagrams and data is lack of interaction and cooperation with users, and the image and appeal are not strong. It is not intuitive and 3D to show the operation status of electrical equipment in the substation, and it is difficult to adapt to the requirements of intelligent substation design and visual management.

Visual display based on 3D modeling technology can enhance the vividness and appeal of the picture, and make the interface more consistent with people's thinking mode and visual habits [2]. Display all kinds of data and relevant information of the substation in an intuitive and visual way, so that the staff can quickly and accurately understand the status of the equipment, and provide visual platform support for data analysis, decision optimization and other applications. 3D modeling technology has also become the focus of operation and maintenance and other business departments with its interactive, intuitive and 3D characteristics.

In recent years, the power grid companies and their direct subordinate units have gradually carried out the research and application of 3D visualization, such as the use of 3D laser modeling and 3D realistic modeling and other technologies to establish substation model, which has realized the further...
application of visualization [3, 4], but the cost of 3D laser modeling is high, and there is a blind area for 3D realistic modeling, which limits their wide application.

This paper uses a combination of software modeling and realistic modeling for 3D modeling. For key electrical equipment, software modeling is used to view the structural relationship and operating status of electrical equipment, so that staff can quickly locate the fault location and analyze the cause of the fault. For the panoramic display and inspection of the substation, the realistic modeling method is adopted, and the substation is inspected in combination with the installed monitoring equipment to achieve a comprehensive display of the real scene on site. By integrating the basic information and test data of the substation equipment into the 3D model scene of the substation, and developing the 3D visualization function, users can view the operating status of the equipment from multiple perspectives, and provide an effective basis for intelligent management and auxiliary decision-making of the substation equipment.

2. 3D modeling technology

3D modeling is one of the key technologies for the information platform to realize the 3D visual display effect. At present, the methods of 3D modeling of substations mainly include 3D laser scanning modeling, 3D realistic modeling and 3D software modeling.

2.1. 3D laser scanning modeling

Laser scanning modeling technology uses laser radar equipment to scan target objects, quickly convert realistic information into point cloud data that can be processed, and then perform point cloud splicing and image matching on point cloud data. Error analysis and Refined processing such as model editing and modification finally builds a high-precision, high-resolution 3D model of the target object.

With the continuous maturity of 3D laser scanning technology on the ground, its applications are becoming more and more widespread. The measurement accuracy of the data obtained by the lidar is very high, which is suitable for high-precision topographic surveying, engineering surveying, 3D measurement and modeling of transmission lines and channels. The massive point cloud data obtained can be used for more detailed local expression of substation architecture, routing, etc., and has good detail expression. The characteristics of non-contact measurement and its penetrating ability make it well applicable to some complex structures and dangerous working environments. However, the laser scanning-based substation modeling method has a large field operation intensity, a large amount of data processing workload, and a low modeling efficiency. It has a long loading time and is not smooth when browsing 3D scenes, and the laser radar equipment used is expensive. The model is limited in the application and promotion of substation visualization.

2.2. 3D realistic modeling

3D realistic modeling is a 3D virtual display technology based on image reconstruction. It uses a professional digital camera to shoot selected scenes from multiple angles, and then uses image processing technology to extract the 3D space information of the target from a single image or image sequence. Finally achieve the 3D reconstruction of the target [5].

3D realistic modeling technology is not limited by the shape, state and size of the target, and does not need expensive equipment and instruments. Through digital camera, 3D data with real texture can be obtained, and realistic pictures are used to build the whole 3D space. When customers browse the 3D scene interface, they are just like on-the-spot investigation, which has higher simulation degree and stronger immersion sense. It is suitable for large-scale urban 3D modeling, transmission line channel modeling and some 3D engineering measurement applications with lower accuracy requirements. The low cost, real model and fast generation of 3D scene modeling greatly reduce the technical threshold and cost of 3D modeling, which is the key research direction in the next few years. However, due to the use of visible light measurement in the 3D realistic modeling technology, it can not show the internal structure of the target and the modeling accuracy is insufficient through the image taken to build the
model, which is suitable for some substation visualization applications with lower accuracy requirements.

2.3. 3D software modeling

3D software modeling technology is based on the digital pictures of substations, design drawings and factory equipment drawings, and the use of professional software such as AutoCAD, 3dMax, Maya, etc., uses cubes, cylinders, cones, etc. to build 3D models of various electrical equipment in the substation in a certain proportion. Then set up the 3D scene model of the substation by setting the model texture and material, and stitching the electrical equipment model [6].

The 3D software modeling technology directly selects the feature model, which is not restricted by the target shape and state. It does not require professional measurement and expensive equipment on the site, and the cost is reduced. Refined modeling of equipment components can objectively and correctly reflect the internal structure and operation principle of the equipment, which can more realistically restore the structural composition of electrical equipment and display it independently, so that staff can quickly lock the fault location and analyze the cause. The 3D software modeling technology can truly restore the target's composition structure, realize the target's split analysis, and the details are expressive and interactive. However, the real scene modeling of the whole station with the digital pictures and design data of the substation has the disadvantages of long modeling time and complicated operation, which cannot meet the requirements for the accuracy and efficiency of 3D modeling of large and complex environments. Therefore, the 3D software modeling technology is suitable for small areas or visualization applications for some devices.

2.4. Comparison of Three Modeling Technologies

A comparative analysis of the three modeling techniques from several perspectives, such as cost, accuracy, and application scenarios, shows the following table.

| Contrast item        | Laser scanning modeling | Realistic modeling | Software modeling |
|----------------------|-------------------------|--------------------|-------------------|
| Modeling efficiency  | Medium                  | High               | Low               |
| Model accuracy       | High                    | Low                | Medium            |
| Modeling prices      | High                    | Medium             | Low               |
| Part reduction       | Medium                  | Low                | High              |
| Color texture        | Medium                  | High               | Low               |
| Visual effects       | High                    | Low                | Medium            |
| Application scenario | Large-scale modeling    | Large-scale modeling | Small-scale modeling |

2.5. Substation modeling technology

Substation routine inspection operations are an important part of substation operation. To achieve unattended substation use 3D modeling technology to establish a visual application platform, users do not need to visit the inspection site in person, and can remotely interact with the real scene through the platform. The main application scenarios of 3D modeling technology in substations are 3D roaming patrols and key equipment condition monitoring. The modeling content is shown in Figure 1.

The substation has the characteristics of irregular shape and huge number of equipment, complicated lines, etc., which makes the 3D ground feature model a large amount of data and difficult data organization. The establishment of a 3D model of the whole station is not only costly, but also requires a lot of buffer space when loading. Limited by software and hardware resources, the browsing load is slow and the user experience is poor.
According to the main application scenarios of 3D visualization of substation, this paper combines the characteristics of each modeling technology, and adopts the combination of software modeling and realistic modeling. The software modeling is suitable for the scenarios with small scope and high precision requirements. For the condition monitoring of key electrical equipment, the software modeling method is adopted. The internal structure of electrical equipment can be analyzed by assembling equipment components to establish the overall model. The real scene modeling is applicable to the scene with large scope, low cost and low precision requirements. For the panoramic display and patrol of the substation, the real scene modeling method is adopted, which can restore the real application scene of the substation equipment, and can also display the electrical equipment interactively.

3. Architecture design of visual monitoring platform

This article starts from the actual needs of intelligent substations, performs 3D modeling and information extraction based on electrical equipment in the substation, classifies and creates model element libraries, restores virtual scenes with monitoring equipment deployed on the site, and establishes 3D visualization of substation equipment with information interaction capabilities. The system can realize advanced applications such as real-time viewing of operation information, perspective analysis of equipment defects, and roaming inspection. The substation equipment status information visualization system adopts an open and extensible architecture design. The system architecture is shown in Figure 2 and is divided into a data layer, a service layer, and an application layer.

![Figure 2. Architecture of visual monitoring platform](image-url)
The data layer adopts standard model library, aiming at massive data management applications, and uses data read-write separation design, so that the data access layer can continuously provide efficient and stable services, and improve the efficiency of data utilization. Based on the extensible data layer, a unified data model is designed, and a business database and a model database are established. According to the development rules of data access service, a data access service suitable for the business needs is developed, which provides the data access foundation for the advanced micro services of the service layer. The data source of model database includes 3D realistic modeling data and 3D software modeling data. The data source of business database includes pre operation information, operation information, maintenance test information, etc. the specific content is shown in Figure 3.

![Figure 3. Business database data source](image)

The service layer includes interface services and application services. Application services provide support for the platform's application functions. Using the Spring Cloud technology framework, advanced microservices are developed at the service layer and service registration is performed. It has the characteristics of miniaturization of particles, singular responsibility, isolation of operations, and management automation. Microservices include comprehensive statistical analysis of equipment status information, monitoring equipment management and configuration, and equipment fault diagnosis and analysis. Interface service refers to the data integration interface between the platform and external systems, which is used to obtain and share business data.

The application layer provides users with a visual operation interface. Users can call related operations for 3D visualization management of the substation, which mainly includes functions such as roaming inspection, information query, data display, defect alarm, and structural perspective. The visual display of the substation equipment can not only view the 3D model of the substation equipment, but also display the monitoring equipment model and monitoring data deployed on the substation equipment, and more intuitively check the operation status of the substation equipment.

4. Visual monitoring platform application

The visualization monitoring platform of substation equipment provides 3D visualization display of comprehensive information such as operation status, identity and fault of substation equipment through integration of substation equipment account, intelligent monitoring data and 3D modeling data, so as to provide basis for intelligent management and auxiliary decision-making of substation equipment.

4.1. Equipment property management

Manage the equipment attributes by establishing the relationship between the equipment account and the 3D model. Account information includes: equipment number, equipment name, equipment type, voltage level, power station, interval, etc. it can realize the intuitive display of account information such as equipment component model and specification in 3D scene, provide auxiliary support for maintenance management personnel and field staff, and improve the utilization rate and maintenance efficiency of spare parts by using account data.
4.2. Model management
There are various types and structures of substation equipment. By establishing a model library, equipment component models can be accumulated, providing a basis for reproducible 3D visualization. The process of assembling the parts into a whole device is shown in Figure 4:

![Equipment assembly flowchart](image)

**Figure 4.** Equipment assembly flowchart

The 3D display also contains the status information of the electrical equipment. This requires that the 3D model can freely add monitoring devices, edit the location of monitoring points, and establish the relationship between electrical equipment and monitoring devices. Users can dynamically adjust the monitoring items, number and location of monitoring points, select the shape and color of the model, flexibly respond to changes in the actual environment, improve the authenticity and flexibility of the model, and improve the user experience.

4.3. Multi-dimensional display of substation equipment status
Multi-dimensional information such as device attributes, sensor attributes, real-time monitoring data, and fault alarms are integrated and displayed in the 3D scene of the substation equipment, so that users can more intuitively understand the device operating status. When the sensor detects abnormal data, the color of the sensor will change. Users can click on the sensor to view the monitoring data graph, data trend graph, and alarm information. The visual effect is shown in Figure 5:
Figure 5. Multi-dimensional display of substation equipment status

For the electrical equipment with defects, the system can locate and display the abnormal parts locally, and use different colors to indicate the severity of the defects, so that the analysts can better perceive the defect location and fault level of the substation equipment. The equipment defect alarm is shown in Figure 6:

Figure 6. Substation equipment defect alarm
4.4. Equipment Perspective

Building component model library of key equipment, a detachable 3D structure model of the equipment is constructed by form of component assembly, according to the structural relationship and spatial orientation of the component, the split model of equipment is displayed in the 3D scene, so that users can understand the internal structure of the equipment quickly and vividly. When a defect is located in a part of the equipment, the user can diagnose and analyze the fault type in combination with the internal structure of the equipment, which can provide reference for expert decision-making analysis. The perspective interface of equipment is shown in Figure 7.

![Equipment Perspective](image)

**Figure 7.** The perspective interface of substation equipment.

4.5. Roaming inspection

The 3D models of substation equipment, sensors and station environment are established by 3D realistic modeling technology, which can reflect the characteristics and spatial relationship of substation facilities and equipment truly, and the 3D scene suitable for remote roaming inspection is constructed as shown in Figure 8.

Roaming inspection includes path roaming and autonomous roaming. Path roaming refers to the user completes the patrol task automatically under the traction of the interface navigation according to the preset patrol route of the system, Autonomous roaming refers to the user performs unlimited and selective inspection in the scope of 3D scene by controlling the forward, backward, and steering independently through the mouse. Roaming inspection can help the operation and maintenance personnel to check the specific situation of the substation facilities and equipment at any time, discover and deal with the hidden trouble in time, and realize the unmanned inspection of intelligent substation.

![Roaming inspection](image)

**Figure 8.** Roaming inspection of substation equipment.
5. Conclusion
In this paper, the visualized monitoring platform for substation equipment is built by the combination of 3D realistic modeling and 3D software modeling technology. Through the precise modeling of electrical equipment, the 3D display and perspective management of equipment status can be realized. Visualization analysis can be carried out on the key areas. Relying on 3D realistic model, we can use intuitive and interactive operation for equipment inspection, so that users can grasp the distribution and the utilization situation of equipment more accurately. The 3D visualization platform has good practicability, which provides a new method for visual monitoring and diagnosis of equipment defects, improves the level of integration and intelligence of substation information system, and improves the visual experience of user greatly.

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