ISSN: 2414-1895 DOI: 10.6919/ICJE.202005_6(5).0043

Digital Model of Substation Inspection System Based on Digital Twin

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Abstract

Intelligent substation is the basis of the intelligent and highly secure operation of power grid. Patrol intelligent substation is an important part of operation and maintenance work. In order to reduce the work of operation and maintenance personnel or realize the safe operation of unattended intelligent substation, digital twin brings technical means to patrol substation. Based on the digital twin theory, according to the patrol inspection route and the substation environment, combined with the digital twin technology and the application of digital key technology, the synchronous communication of virtual and real data and the virtual and real modeling technology are mainly carried out to realize the virtual real-time digital simulation of entity, and the path optimization algorithm is designed. The experiment shows that the robot or the inspector can extract the inspection path effectively, and the path optimization algorithm can reduce the energy consumption of the person or the machine.

Keywords

Digital twin, Intelligent substation, Digital mod, Inspection system.

1. Introduction

Digital twin is an information technology that has emerged in recent years. It refers to the integration of objects, models and data in virtual space. Simulation model, the virtual model is completely consistent with the physical entities in real space, and is a mapping of physical entities in real space[1]. The digital twin combines real-time data from its physical copy with an interactive visual interface. This provides an unparalleled level of monitoring. This enhanced visual interaction improves the ability to generate actionable insights based on data. By combining the monitoring functions provided by digital twins with machine learning algorithms, automated cause analysis can be performed to prevent recurrence of work failures and quality deviations.

With the development of smart grids, the type and number of primary equipment in the power grid continues to increase, and equipment operation and maintenance workloads also increase rapidly. The inspection frequency of different types of substations is also different, and the routine inspections of AC UHV substations are not uncommon every two days. At 1 time, the comprehensive inspection shall be no less than once a week, the professional inspection shall be no less than once a month; the routine inspection of 750kV substation shall be no less than once every 3 days, and the comprehensive inspection shall be no less than every 15 days 1 time, no less than one professional inspection every quarter[2]. Robot technology is developing rapidly and can replace manual tasks that are difficult to operate and require high precision. More and more attention has been paid to the industrial field. Among them, substation inspection robots are widely used in power systems. After years of development, many different types and functions of inspection robots have been introduced and

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promoted[3-4]. However, the current products need to be improved in terms of inspection capabilities, emergency strategies, data analysis and sharing. They cannot meet the needs of the energy Internet construction, and fail to fully integrate with emerging technologies such as artificial intelligence and big data to improve inspection intelligence. Degree[5]. With the high-quality development of the economy, the scale of the power system is constantly expanding, and the requirements for system operation stability and state feedback timeliness have been continuously improved[6].

Operation and maintenance personnel need to standardize the routes inspected by inspectors, and the widespread application of intelligent machine inspection substation equipment and optimization of the route of substation inspection routes can also reduce the energy consumption of personnel or machinery. During the inspection of personnel or robots, the information is displayed and stored separately. The overall effect of monitoring is not good. The information lacks a close connection with the actual model. Such an information management mode will cause a lot of inconvenience to maintenance. This paper proposes a digital model of a substation inspection system based on digital twins, and introduces the overall digital model design scheme. It includes multi-domain modeling comprehensive technology and new information technology to build digital twins that can accurately simulate physical entities. Digital twins The model realizes the patrol process simulation of inspectors, and based on this, an optimization algorithm for the inspection path is designed.

1.1 Overall design plan

The digital twin patrol system introduced in this article is mainly composed of three parts: the substation field equipment layer, the core technology and the functional modules.

The main functions of each part of the system are as follows:

1) Substation field equipment layer: For a smart substation, the equipment layer mainly contains a set of objective entities, such as the "people and equipment object ring", which is responsible for the daily inspection activities of the substation and provides the first-time video data and sensor information. Spatial data, such as the geographic location of the equipment in the substation, physical information about human trajectories, temperature and other environmental data.

2) Core technology layer: Virtual reality synchronization system technology is mainly virtual synchronization communication, lightweight processing of models and virtual reality synchronization simulation technology. Virtual and real synchronous communication is a technology based on the integration of data acquisition and transmission in substations. The purpose is to achieve virtual and real synchronization. The basis of condition monitoring: model lightweight technology is the true mapping of the model layer to the physical layer, and improves the application performance of the model through lightweight processing.

3) Function module layer: According to the research and application of core technology, it can display the status information of substation inspections in an all-round way, improving the intelligent management level of personnel inspections in smart substations. Through related applications, functional modules such as personnel patrol simulation and parameter monitoring can be implemented to help intelligent substations better detect and predict health conditions and improve intelligent management of substations.

1.2 Virtual synchronous communication technology

Data acquisition and fast transmission of the underlying equipment of the intelligent substation are the basis of the entire digital twin system. The basic data of the device is a real-time dynamic surreal mapping of the physical entity system. For system developers, the real-time data of a large number of heterogeneous devices is the most important and basic element in the entire digital twin system. Based on this important part, this system research application program uses virtual synchronous communication technology, which is the development of data acquisition and transmission integration. System status information is transmitted securely and in real time through the platform's fast and reliable information transmission network design. For equipment of smart substation:

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1) Data industry collection: The KEPServerEX industrial connection platform for device-side data collection provides a single source of multi-channel industrial automation data for upper-layer application development. OPC is an industry-specific protocol used to solve the communication of various device drivers in the production line. After establishing a heterogeneous device network, each device is located on the same network segment, and the key steps of KEPServerEX can be easily configured. Establish real-time data of multi-dimensional channel acquisition equipment to realize the data exchange connection between the OPC client and the PLC address of each device in the substation.

2) Web service interface for data communication: Perceived data transmission is the key technology to realize virtual and real synchronous communication. This time, the web service-based messaging mechanism is used to access the network. In the web service architecture, you can find and call the services provided by the service provider, and the browser can operate the service requester role. During data transmission, the perceived data is stored in the upper-level computer platform. It is grouped and stored in JSON format, and provides an outbound interface. With Unity3D as the client, it requests interface data, implements synchronous communication between device layer data and model layer, and realizes the basis of virtual space and real space data mapping.

2. Construction and simulation of digital models for smart substations

2.1 Lightweight Construction Model

When using commonly used modeling software such as Solidworks, CATIA, Pro / E for modeling, problems such as improper operation or too high degree of refinement of the model will cause a lot of redundancy in the points, lines, and surfaces of the model. If the number of hidden objects is too large, direct application in the system will consume a lot of memory and computing resources, which will cause problems such as slow loading speed, stuttering, and incomplete display, which will seriously affect the user experience. There is an effective model lightweight method. Export models made by other modeling software as .stl files, then import 3dmax software, delete redundant points and lines, and export to the required format again. You can also use the Polygon Cruncher tool to modify the model face and point values. This method can significantly reduce the size of the model file, but in order to preserve the basic structure of the model, the number of points and faces should not be reduced too much. This system uses:

1) In the industrial modeling software, create a virtual geometric model in the industrial modeling software Solidworks, and save the corresponding .stl format file in time, and save the corresponding attribute parameters;

2) Import the saved .stl format file into 3DMax, and then judge the imported model from the point-to-point threshold to determine whether there are extra dotted lines. If so, rebuild the model. If it does not exist, proceed directly to the next step.

3) When obtaining a lightweight model that eliminates redundancy, a UV mapping correction is required to ensure the similarity of the models.

4) Finally, export the model and save its corresponding geometric parameters, lighting settings, picture settings, etc.

2.2 Dynamic Mapping Simulation of Digital Model of Substation

The digital twin simulation of the substation model is based on real-time data acquisition and lightweight models of the substation scenario. Based on the establishment of a rule database corresponding to the twin data, the virtual model and field devices are arranged in the data processing platform to realize the combination of virtual and real. The real-time simulation of the virtual model is driven by real-time data acquisition, transmission, and classification, as shown in Figure 1. This model simulation platform uses Unity3D driver to edit the 3D model twice and import the FBX file generated by 3DMAX into Unity3D. If there are missing textures or the model is incomplete during the import process, you can consider exporting in 3DMax first. .stl format, and then converted to FBX

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file through .stl, so that the situation of missing textures is resolved. After the above process, the simulation of equipment and scene is more realistic, and the ability of human scene fusion can be improved. The corresponding real-time information is obtained by continuously calling the real-time database. Combined with Visual Studio's C # program, the obtained single-column data is converted into JSON format to achieve accurate real-time information acquisition.

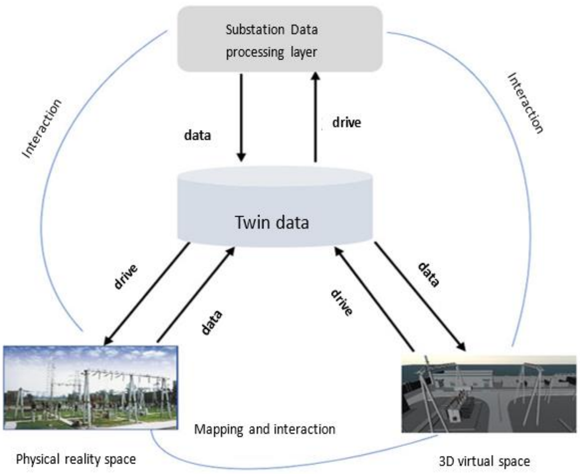

Figure 1.Virtual model driven simulation architecture of Substation

During the simulation of the twin model, the inspection path of the inspector or robot is extracted and optimized. The path extraction algorithm can be implemented by using C # code in Unity3d. It can be optimized for the extracted trajectories. According to their environmental modeling methods, path planning methods can be divided into: viewable method[7], grid method[8], free space method[9], voronoi method[10], etc.; For: Floyd algorithm[11]. At present, the commonly used mobile robot path planning algorithms mainly include particle swarm optimization (PSO) algorithm, genetic algorithm[12], ant colony algorithm[13], fuzzy control[14], and so on. Compared with other algorithms, the PSO algorithm has the advantages of fast convergence speed and simple parameter setting, etc. In recent years, it has received widespread attention in the field of path planning. For the substation equipment inspection path optimization problem can be described as: given L equipment intervals and the plane position coordinates of each equipment interval, solve a shortest path through each equipment interval. The mathematical model can be expressed as: assuming a set of L device intervals G = {G1, G2, ..., Gl}, and the distance between every two devices is d (Gi, Gj), a Hamilton loop is required to be solved, so that The value is the smallest. This algorithm is inspired by the regularity of the bird's cluster activity, and is a simplified model established by using swarm intelligence. The particle swarm optimization algorithm is based on the observation of the behavior of animal clusters, and uses the information shared by individuals in the cluster to make the rule of movement of the entire cluster produce a rule-based evolution process in the solution space, and then find the optimal solution .

A particle swarm optimization (PSO) algorithm was used to simulate bird predation: Suppose a group of birds were randomly looking for food in a certain area, but there was only one piece of food in that area. The birds don't know the exact location of the food, but they know how far the current location is from the food, so the best strategy to find food is to search the surrounding area of the bird that is currently closest to the food to get the food location. Each particle in the particle swarm algorithm represents a potential solution to the problem, and each particle corresponds to a fitness value determined by the fitness function. Use the motion experience of particles themselves and other particles to dynamically adjust the speed to achieve individual optimization in the solvable space. Assume that in an m-dimensional space, there are n particles that make up the particle group X = (X1, X2,…, Xn), where the position vector of the i-th particle is Xi = (Xi 1, Xi 2,…, Xi n), the velocity

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vector is Vi = (Vi1, Vi2, ..., Vin), and the optimal position of the particle during the m-dimensional space movement is Pi = (Pi1, Pi2, ..., Pin). The optimal position that all particles pass is represented by PG, then PG = (PG1, PG2, ..., PGn). The velocity and position evaluation functions of the particles after each iteration are expressed by equations (1) and (2), respectively, that is,

$$Vi\,(k + 1) = wVi\,(k) + c1r1\,[Pi\text{-}Xi\,(k)] + c2r2\,[PG\text{-}Xi\,(k)] \tag{1}$$

$$Xi\,(k + 1) = Xi\,(k) + Vi\,(k + 1) \tag{2}$$

Where k is the number of iterations; w is the inertia weight; c1 and c2 are acceleration factors; r1 and r2 are in the range of [0,1]; internally follow a uniform distribution of random numbers; wVi (k) is the momentum part; The initial force of particle inertial motion; c1r1 [Pi-Xi (k)] is the cognitive part that represents the memory behavior of particles and stimulates particles to move to the best position they find; c2r2 [PG-Xi (k)] is the representation The social part of the interaction between particles and conducting other particles leads other particles to move towards the optimal solution in the particle swarm[15]. The three parts balance each other and determine the performance of the particle swarm optimization algorithm. In the process of iterative calculations, in order to prevent particles from speeding up blind search, the particle speed should be limited, and the particle position is generally limited to the range of [-Ximax, Ximax].

Figure 2 is a random trajectory chart, and Figure 3 shows the optimal solutions obtained by using the proposed PSO algorithm to solve the substation equipment patrol path optimization problem after 100, 200, 300, and 500 iterations, respectively. Happening. It can be seen that as the number of iterations increases, the distance of the shortest patrol path gradually decreases, reducing the energy consumption of people or machines. The solution results converge to the optimal, and Figure 4 is the iterative optimal shortest planning path.

3. Experimental results and simulation

The model of 110KV substation in Runan, Pingdingshan, used in this paper, solves the problem of unified collection, management and transmission of substation information. Through the corresponding model lightweight processing, the virtual and real synchronous dynamic simulation digital model is completed, and the path extraction of the inspectors is completed. Digital application research has realized the basic work of digital intelligent inspection and laid the foundation for the development of more digital twin technologies for future applications.

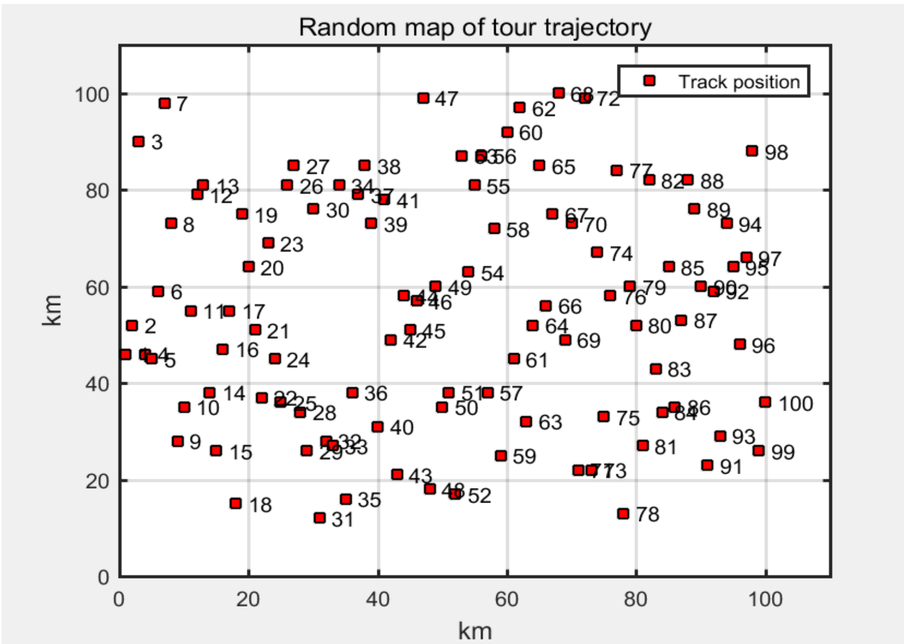

Figure 2.Random map of tour trajectory

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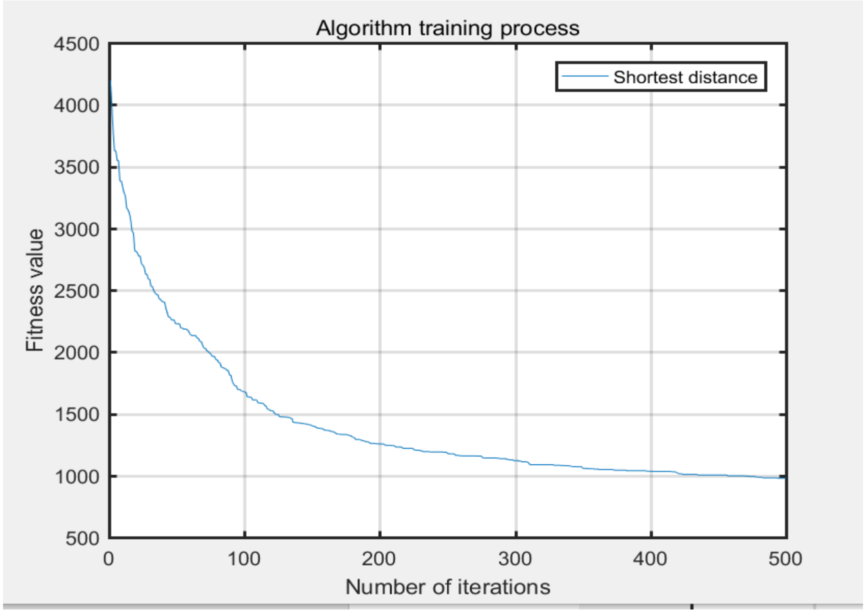

Figure 3.PSO algorithm iterative shortest distance

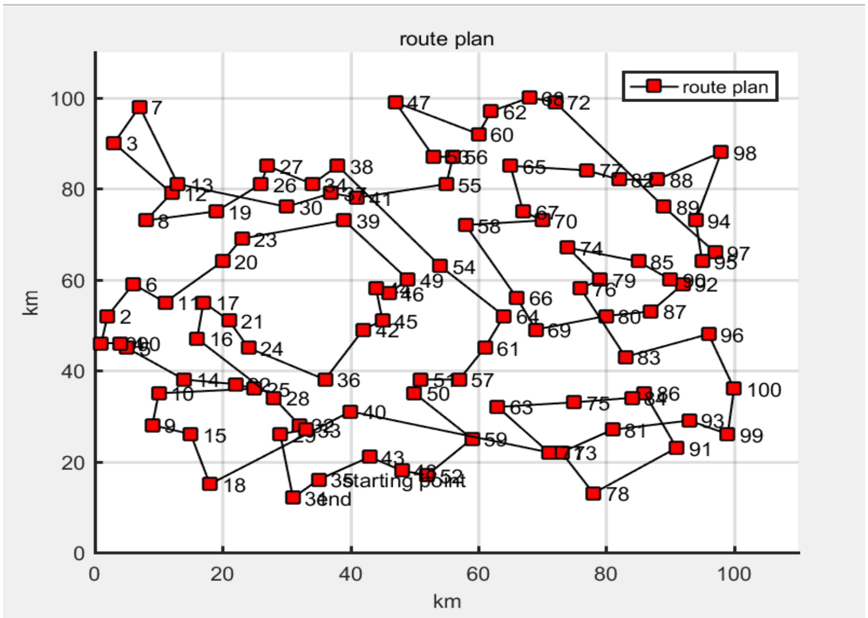

Figure 4.Optimal shortest path of iteration

Figure 5.Three dimensional model of Intelligent Substation

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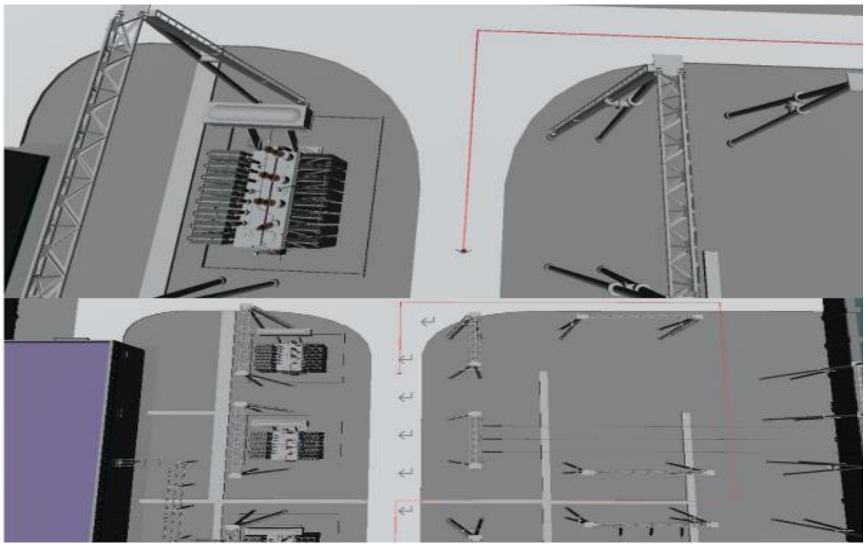

Figure 6.Real time extraction path map of Substation

As shown in Figure 5, it is the model development diagram of the digital simulation of the substation. As shown in FIG. 6, according to the real-time inspection personnel or the routine inspection work of the machine, the inspection path is extracted, and the correctness supervision and optimization can be performed through the extracted path.

4. Conclusion

In the application of digital twin technology in intelligent substations, this paper mainly performs the synchronous communication of virtual and real data and virtual and real modeling techniques to achieve the virtual digital twin model of the substation inspection system. The interface of the equipment on the intelligent substation, real-time data information is collected to the data processing platform; digital simulation development and virtual-real mapping are implemented on the Unity3D development platform through real-time port calls and lightweight model processing to implement dynamic simulation of the inspection process of inspectors, paths Extracting and optimizing the path according to the path optimization algorithm can reduce the energy consumption of people or machines.

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