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3D Digital Simulation System of Power Transmission and Transformation Line based on Digital Twin

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ABSTRACT

In view of the problem that the original system cannot truly display the geographical environment of engineering, the design method of the 3D digital system of power transmission line based on digital twin is studied. In the hardware design, the transmission line network architecture is arranged, embedded in the OPC-UA server, and the sensor node location is bound. In the software design, the spatial database of transmission and transformation lines is established, the digital twin 3D virtual model is constructed, and the design of 3D digital system is completed. With complex area transmission and transformation line construction project as the object of experiment, the experimental results show that: select the location of the multiple scenarios line segment distance measurement, two groups of traditional methods to the actual distance measurement error, generated topographic map deformation, and the system can completely restore the transmission line segment distance, has the practical application effect.

KEYWORDS

Power Transmission and Transformation Line; Environmental Characteristics; Digital Twin.

1. INTRODUCTION

China's economic and social development is relatively rapid, industrial and industry, agriculture and service industry are entered a new development situation. With the deepening of the urbanization process, the demand for power is gradually increasing, and the layout and construction of transmission and transformation lines is more important than ever before. Electric power engineering construction is one of the important projects of economic construction, plays a very important influence on the national economic development, the current power engineering construction means and maintenance way, has been difficult to meet the requirements of the development of smart grid, need to modern information management and technology design, to improve the efficiency of the construction of power transmission and transformation project. Modern information has completed the transformation and development of digitalization and visualization, and will better interact and integrate the physical world and the information world. In the operation of transmission and transformation lines, there will be a large number of electronic equipment. Only by ensuring its operation in safety parameters can the stability of the transmission power grid be maintained, so that the overall condition of the line should be monitored and managed[1]. Digital twin technology is a kind of synchronous digital mirror in the physical world, which can be derived from the analysis of data, feedback the optimized data results to the physical world, and select the parameters of the equipment that need to be supervised or controlled. Digital twin technology can conduct digital

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simulation of virtual space through the preset of the overall environment, restore the overall connection between equipment and lines, establish a virtual model equal to the actual proportion, endow it with physical attributes in reality, and realize the roaming function in the three-dimensional scene. This technology has been studied at home and abroad. For example, Eric J.Tuegel and others have studied the aircraft structure life prediction model based on digital twin technology, using the refined model of a single aircraft to integrate the calculation of structural deflection and temperature, and obtained better results; The Chinese scholar Chen Siyuan and others also proposed the MPS intelligent control system [2] based on digital twin. Taking this paper as the research premise, based on the digital twin technology as the design, this paper establishes a three-dimensional digital simulation system for the transmission and transformation lines to provide a theoretical basis for accurate positioning and visual management.

2. HARDWARE DESIGN OF THE 3D DIGITAL SYSTEM

The digital system of power transmission and transformation lines, based on the LAN environment, can directly access the information and set two communication modes. All the departments required for line construction are connected in the same group of network servers, and the data server interface [3] is configured. The specific architecture is shown in Figure 1. According to Figure 1, in order to realize the power demand, the transmission and transformation lines are intelligently network managed. And the incoming data are analyzed in real time through the storage of power data information, and the electricity data can be queried at any time when the power data is released in the network.

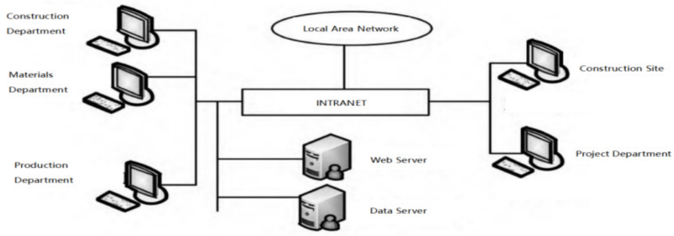


Figure 1. Network architecture of power transmission and transformation lines

The digital twin three-dimensional system is planned to be built, which is necessary to restore the normal operation state of the transmission and transformation line, and embed the monitoring server in OPC-UA protocol mode to carry out unified monitoring of the power equipment. For different types of operating devices, you can correspond the power data to the address space in the server, connect the client with the server, and directly communicate the data, as shown in FIG. 2 [4]. According to FIG. 2, the client wants to connect with the discovery server to obtain the data list through the server to realize the data flow of power. The OPC-UA server is registered through the REGISTER-SERNER method. After finding the connection between the two, the client can complete the power data query through the server, so as to obtain the description information of the relevant transmission and transformation lines.

The power data generated by the sensors in the transmission and transformation line will be displayed in the form of nodes, which can be bound in the corresponding server to classify the data attributes represented by each node object and obtain the operation situation [5] of different line positions. With a kinds of information in OPC-UA server, the address space, service model and security model are set uniformly, and a unified data interface is provided to realize the data information access of transmission and transformation lines and provide communication guarantee for the operation rate of power data. The address space consists mainly of the server nodes, which are also known as the basic unit. Different nodes have specific properties and decisive properties, binding [6] to object nodes and variable nodes and method nodes respectively. The client can obtain the data variables in the server through the form of subscription and reading, and store the data of the power line in the variable node, and the data change of the node can directly represent the power operation state, transfer the two into the server for configuration, and the sensor parameters can be uniformly configured.

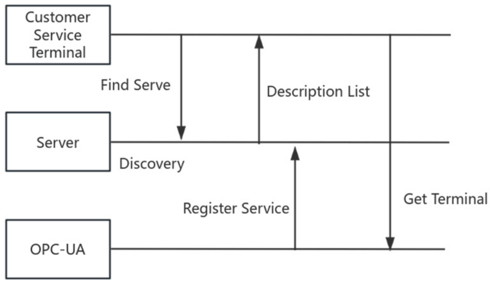


Figure 2. Embedded server step

3. HARDWARE DESIGN OF 3D DIGITAL SYSTEM

3.1. Establish the Transmission and Transformation Line Space Database

The spatial structure of the geographical object of the transmission and transformation line can be represented by spatial data. With the coordinate data as the geometric positioning feature, the wire location of the transmission line is arranged, and the line voltage of the power system can be marked. To calculate the fixed position of the database, the folding error should be controlled in the minimum interval to ensure the simulation order in the process of application of the model. Set the coordinates of the opposite side in three-dimensional Euclidean space as (q_i,q_j), and fold the set of associated triangles as planse (i, j).

The fixed position in the new position is expressed as w [x, y, z] e, and the vertex is defined under the quadratic error measure, to the sum of each area, as follows [7]

$$\Delta(\overline{q}) = \sum_{r \in planes} (r^e \overline{q})^2 \tag{1}$$

Where the triangular square area of planse (i, j) is r=(a,s,d,f)^e. The equation is:

$$\begin{cases} ax + sy + dz + f = 0 \\ a * a + s * s + d * d = 1 \end{cases} \tag{2}$$

Convert it as:

$$\Delta(\overline{q}) \begin{cases} = \Delta\left(\left[x, y, z\right]^e\right) \\ = \sum_{r \in planes} q^{-e}\left(rr^e\right)\overline{q} \\ = r^{-e}\left(\sum_{r \in planes} T_q\right)\overline{q} \\ = q^{-e} Y \overline{q} \end{cases} \tag{3}$$

Where T_q is a symmetric matrix of 4 * 4, a triangular error matrix, as follows [8]:

$$T_q = {}^q q^e = \begin{bmatrix} a^2 & as & ad & af \\ as & s^2 & sd & sf \\ ad & sd & d^2 & df \\ af & sf & df & f^2 \end{bmatrix} \tag{4}$$

The error matrix of the folded 3D model, expressed as Y, is as follows:

$$Y = \sum_{r \in planes} T_q = \begin{bmatrix} a^2 & as & ad & af \\ as & s^2 & sd & sf \\ ad & sd & d^2 & df \\ af & sf & df & f^2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & y_{13} & y_{14} \\ y_{12} & y_{22} & y_{23} & y_{24} \\ y_{13} & y_{23} & y_{34} & y_{34} \\ y_{14} & y_{24} & y_{34} & y_{44} \end{bmatrix} \quad (5)$$

Where: all triangular error matrices in planse (i, j) are summed to obtain the matrix Y. According to the special form of the matrix, the folding error is obtained, and the spatial data existing in the transmission and transformation lines is sorted to obtain the spatial database.

On the basis of the realization of real-time mapping, the virtual and real exchange technology is used to realize the conversion of the power data, so as to calculate the state and utilization efficiency of the power equipment, and provide visual data for the hardware equipment.

3.2. Construct the Digital Twin 3D Virtual Model

The larger the magnitude of spatial data, the higher the data demand for location description. In order to accurately describe the information data of transmission and transformation line engineering, the three-dimensional virtual model is established by means of digital twin. According to the operation principle definition of the model according to the digital twin theory, in the operation of the transmission line, the model can control the power supply of the transmission line according to the operation plan, so as to provide the real power service [9]. The specific operation link is shown in Figure 3. The construction of digital twin model is the core of the application of twin technology, which can digitize the construction of the field environment and equipment, and map the production activities of physical equipment in the digital space.

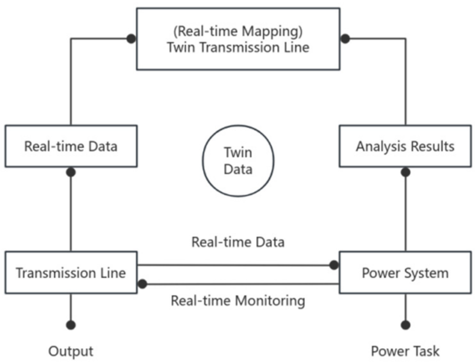


Figure 3. Operation principle of the digital twin model

In the operation of the transmission and transformation line, the equipment is in series, and the structure is connected according to the virtual simulation of the series robot. The reverse solution of the [10] of the virtual robot is realized through the Jacobian matrix. Set x_o axis, y_o axis and z_o axis respectively, and make the kinematic structure vector representation as follows:

$$U = [U_{x_o} \quad U_{y_o} \quad U_{z_o}] \quad (6)$$

Where: the bit vector is expressed as a U. Convert to a pose vector, expressed as an I, as follows:

$$I = [I_{x_o} \quad I_{y_o} \quad I_{z_o}] \quad (7)$$

The translational joints and ends of the joints in the model, referring to the x_o, y_o, and z_o coordinates, perform the degrees of freedom in the three directions, and the end joints are rotated [11-12]around the x_o axis.

Take any base point coordinates to make the joint in the zero position state, the basic offset BASE-OFFSET is the fixed value, and the spatial coordinate relationship is as follows:

$$\begin{cases} U_{x_o} = JOINT[0] \\ U_{y_o} = JOINT[1] \\ U_{z_o} = JOINT[2] \end{cases} \tag{8}$$

Where: JOINT [1] is the joint value of the first set of joints. Positive and inverse solutions are made according to the kinematic theory, as follows: [13]:

$$TRAGET[x_o, y_o, z_o] = \left[U_{x_o}, U_{y_o}, U_{z_o}\right] + BASE - OFFSET[x_o, y_o, z_o] \tag{9}$$

$$JOINT[0,1,2] = TRAGET[x_o, y_o, z_o] - BASE - OFFSET[x_o, y_o, z_o] \tag{10}$$

The constructed digital twin model is compared with the positive and negative solution script of the kinematic robot to obtain the operation data of the transmission and transformation line. So far, the design of the three-dimensional digital system based on the digital twin has been completed.

4. EXPERIMENTAL TESTING AND ANALYSIS

4.1. Establish the Transmission and Transformation Line Space Database

Based on the digital twin technology, the three-dimensional digital simulation system of the transmission and transformation lines is preliminarily realized, and the effectiveness of the system is demonstrated by comparative test. The 3D simulation model of the transmission and transformation line is shown in Figure 4.

Figure 4. The 3D visualization model of power transmission and transformation lines

Generally, these systems mainly have the functions of 3D visualization and 3D analysis. This paper first verifies the 3D visualization function based on Figure 4, which has realized the 3D visualization function, so this paper mainly tests the 3D function analysis in the process of system function test. First log in the system, the basic map function test and the main spatial analysis module are tested for the system, that is, the basic functions such as map display, zoom, and attribute query. The results are shown in Table 1.

Next, the system performs 3D analysis performance of the test. The so-called 3D analysis means that the system needs to provide the user with distance measurement, area measurement, 3D profile and other functions. The test steps are shown in Figure 5.

Test according to the above steps, and the test results obtained are shown in Table 2. Thus, it can be proved that this paper is practical and has the ability of 3D visualization and 3D analysis.

4.2. System Comparison Test

In order to further verify the system performance of this paper, GIS system and panoramic system were selected as comparison system, and distance measurement, area measurement and two-dimensional profile were selected as performance indexes to carry out performance comparison test.

Table 1. Test results of system 3D function analysis

Function	Test instance	Precondition	Controls	Expected result	Test result
Map display	Switch Between Scales of 1:100,000 and 1:50,000	Log in to the System	-	Displays Normally at Any Scale	Consistent with Expected Results
Zoom in or out	Local Zoom In/Out	Log in to the System	Mouse Select Area	Selected Area Shown with Red Border and Automatically Zoomed In/Out	Consistent with Expected Results
	Full Zoom In/Out	Log in to the System	Mouse Double-click, Scroll Wheel	Double-click to Zoom In Overall, Scroll Up to Zoom In, Scroll Down to Zoom Out	Consistent with Expected Results
Attribute Query	-	Log in to the System	Click on Any Part of the Layer with Mouse	Click to Pop up Attribute Box and Show Geographic Attributes	Consistent with Expected Results

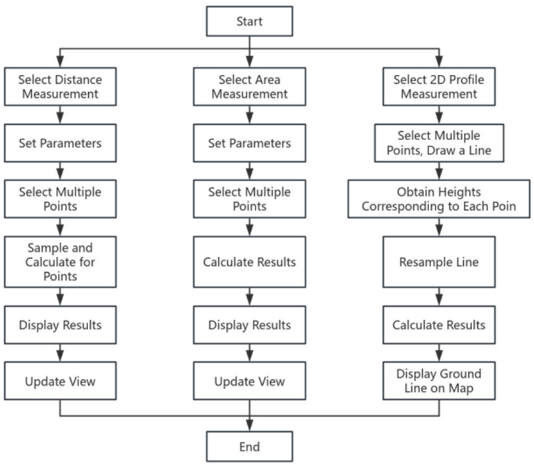


Figure 5. Flow chart of the 3D analysis

Table 2. Results of the system 3D analysis function test

Function	Brief Description	Expected result	Test result
Distance Measurement	Continuously click multiple positions in the scene with the mouse to measure the straight-line distance and ground distance formed by connecting these points.	Display correct length data values	Consistent with Expected Results
Area Measurement	Measure the area formed by connecting multiple points	Display correct area data values	Consistent with Expected Results
2D Profile	Can capture the undulations of a segment of DEM terrain and generate relevant images	Can reasonably generate a 2D profile at the base of the tower	Consistent with Expected Results

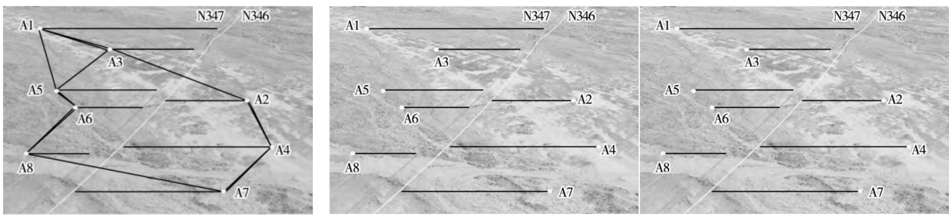
(1) Line distance measurement

With two sets of transmission lines of N346 and N347 as the test objects, multiple data points are arranged on both sides of them, so that the actual distance from the transmission lines is different, as shown in Table 3 below.

Table 3. System 3D Analysis Functional Test Results

Point position	N346	N347
A1	-	198.23
A2	152.23	-
A3	-	204.27
A4	124.45	.
A5	-	245.32
A6	-	256.12
A7	146.77	-
A8	-	274.21

According to Table 3, in the two transmission lines selected, the distance between the two sides is different. It can be seen that most of the points are on the side of N347, and the decimal points are on the side of N346. Through the simulation through the three systems, and the results are shown in Figure 6. According to the content of figure 6, the system can not only monitor the distance on both sides of the distance, but also can use the folding line, the line on both sides of the line, and the traditional system only completed the single direction of point distance measurement, and the distance between two points, which can prove the system has a better distance measurement performance.



(A) System of this paper (b)GIS system (C) Panoramic system

Figure 6. Comparison of the distance results

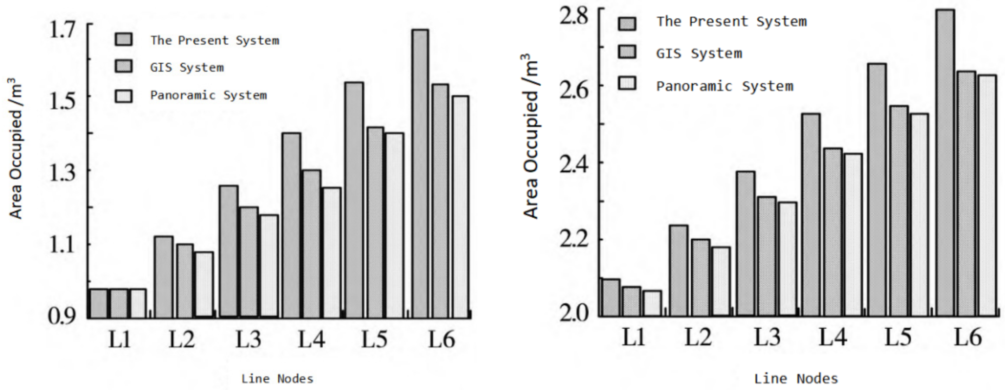
(2) Measurement of the line occupied area

In the two groups of transmission lines, 6 groups of nodes are arranged at the same time, with different nodes as the center, and the separated distance of each group of nodes is increased by 50m successively. The initial node of N346 is 350m in line layout with an occupancy area of 0.98m3, and the initial node of N347 is 750 m in line layout with an occupation area of 2.10m3. Statistics were performed for different nodes as shown in Table 4.

Table 4. Measurement node area / m3

Node	L1	L2	L3	L4	L5	L6
N346	0.98	1.12	1.26	1.40	1.54	1.68
N347	2.10	2.24	2.38	2.52	2.66	2.80

According to the contents in Table 4, after the division of different nodes, the occupied areas occupy 0.14m3, which is connected to three systems respectively, and the area of nodes is counted, as shown in Figure 7.



(A) The N346 line node (B) The N347 line node

Figure 7. Comparison of the occupied areas

According to FIG. 7, the system measurement in this paper is completely consistent with the actual occupied area data, while the two groups of traditional systems have error in the far node distance, which proves that the system has better area measurement performance.

(3) Profile

The node distance will affect the elevation calculation results, and eventually lead to the deformation of the topographic section drawing. Select the design elevation through the above 6 groups of nodes, and simulate the path fluctuation. The specific situation is shown in Figure 8. According to the content in Figure 8, due to the error of the traditional system in the node data reduction, the section drawing is deformed, and the drawing drawing does not change according to the original section drawing. In this paper, the system can connect each group of nodes to completely restore the topographic fluctuation state, which can prove that the profile generated in this paper is more real and has more application value.

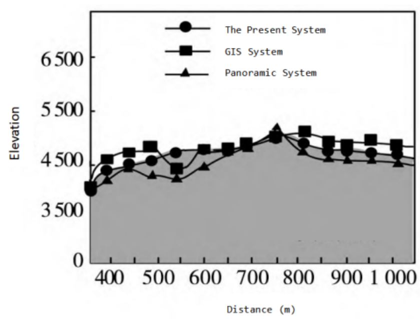


Figure 8. Comparison of elevation change profile direction

5. CONCLUSION

Power transmission and transformation projects have entered a leapfrog development, and most of the new transmission and transformation lines have to pass through complex environments, which need to carry out fine management. Based on the design of digital twin, the transmission and transformation lines are simulated by 3D digital system, and certain results are obtained. Through testing, it is shown that the system can provide a basis for the construction of the line by restoring the real data, copying the terrain line conditions in equal proportion, and ensure the good application effect of the digital system.

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