Transmission line inspection data visualization system based on 3D GIS

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Abstract—In order to meet the needs of safe and efficient patrol operation and maintenance of modern smart grid, aiming at the poor quality of current transmission line patrol inspection, a design method of transmission line patrol data visualization system based on 3D GIS is proposed. By optimizing the system hardware structure configuration combined with 3D GIS technology, the function and structure of transmission line visual management system are introduced. The accurate collection and processing of transmission line inspection data and the display of inspection route are realized by using three-dimensional GIS technology. Finally, the experiment shows that the transmission line inspection data visualization system based on Three-dimensional GIS has higher practicability and accuracy in the process of practical application, and fully meets the research requirements.

1. Introduction
Transmission line visualization is to integrate the information of transmission line tower, corridor environment and the defects and hidden dangers of transmission equipment into a management system[3]. With the progress of data acquisition technology and the development of remote sensing technology, using unmanned helicopter multi-sensor to obtain multi-source data provides a new way for transmission line patrol[2]. UAV transmission line inspection system can not only greatly improve work efficiency, but also reduce field work and line inspection cost. In terms of achievements, it can provide common power grid account data and 3D GIS visual management based on the data. The construction of transmission line inspection visual management system can well solve the problems encountered in transmission line operation and maintenance, improve the efficiency and level of power management, and have good social and economic benefits[3]. However, at present, most power grid transmission line inspection management systems are based on traditional 2D GIS technology. It can not meet the requirements of transmission line inspection data visualization. Aiming at the characteristics of large span of transmission line corridor, wide coverage and large amount of data collected by unmanned helicopter line inspection system, a set of visual management system for UAV transmission line inspection is designed[4]. This paper introduces the architecture and function of visual management system, and expounds three key technologies: data management, data visualization, intelligent diagnosis and fault detection. The application of the system in power grid transmission lines shows that it can realize the functions of rapid browsing, roaming and fault display of patrol massive data, and has achieved good results.
2. Transmission line inspection data visualization system

2.1. Hardware configuration optimization of transmission line patrol inspection data visualization system

There are many technical difficulties in the management of transmission line inspection data by visual management system. The system design needs to meet the needs of project management and visualization\cite{5}. In terms of data, the amount of transmission line inspection data is huge and there are many types, mainly including sensor status data, point cloud data, image, digital elevation model, digital surface model, three-dimensional GIS model data, defect data of line hidden danger diagnosis, etc\cite{6}. According to the above analysis, the logical architecture of transmission line patrol visual management system is divided from three levels: data service layer, internal processing layer and analysis presentation layer\cite{7}. The figure 1 shows the system architecture.

![System hardware structure framework](image)

The core component layer in the figure provides the underlying basic processing algorithm for the system, including basic mathematics library, image processing library, map projection library, 3D GIS Engine and point cloud processing library. Due to the reason of processing pictures and running point clouds, the defect analysis workstation mainly adopts the workstation with high-performance graphics processing ability. The visiting end has direct access to the web site, so there is no restriction on the hardware. The details are shown in the table 1:

| Content                  | Hardware parameters                                      | Purpose                                           | Platform requirements                  |
|--------------------------|----------------------------------------------------------|---------------------------------------------------|----------------------------------------|
| Platform server (1 set)  | Type: rack server                                        | Deploy platform application, GIS application, interface application, etc | RAID5 disk array + WindowsServer 2012 datacenter, + is60up |
|                          | Processor: xeon-e564g                                     |                                                   |                                        |
|                          | Memory: above 64g                                         |                                                   |                                        |
|                          | Hard disk: 3T hard disks, supporting hot plug and dial, more than 7200 revolutions |                                                   |                                        |
| Database server (2 sets) | Installing SQL Server 2012 databases Installing SQL Server 2012 databases | Installing SQL Server 2012 databases              | RAID5 disk array + WindowsServer 2012 datacenter |
|                          | CPU model: core i77820k                                   |                                                   |                                        |
|                          | Motherboard: x299a                                       |                                                   |                                        |
|                          | Memory: ddr3240064g                                       |                                                   |                                        |
|                          | Graphics card: NVIDIA geforce gtx1080                    |                                                   |                                        |
|                          | Hard disk: 256gb solid state + 4tb mechanical             |                                                   |                                        |
| Defect workstation (1 set) |                                                        | Used to deploy pix4d and tree barrier analysis software | Windows 10                     |

Table 1 Parameter setting of system hardware equipment
The system can clearly see the meters and equipment positions in the substation and read them correctly, making up for the short board of untimely reading of equipment data in unattended substation and inaccurate reading of inspection robot, and can conduct background comparison and analysis of data to form a large database, analyze historical curves and find equipment defects. It can view the actual state of the equipment, facilitate the monitoring personnel and operation and maintenance personnel to remotely align and view the unattended substation, and realize the remote inspection, remote analysis and artificial intelligence of the equipment. It can be connected with video monitoring system and security system for equipment appearance and security patrol.

2.2. System software function optimization
On the basis of system integration and debugging, the transmission line patrol visual management system is applied to a UAV patrol transmission line in Guangdong power grid to visualize the faults such as transmission line corridor environment, abnormal heating, abnormal discharge and hardware corrosion. The data to be processed by the visual management system mainly include visible light image data, point cloud data, infrared data and visible light video data. In the system, the first mock exam is used to establish a unified model collaborative management for all kinds of data. The intelligent diagnosis module for laser point cloud, infrared video and visible light and the management module of 3D GIS query and browse are integrated. According to different data sources, the system displays data through three different modules, as shown in the figure 2.

3D GIS data browsing includes 3D GIS point cloud data browsing and 3D GIS model visualization browsing, including rapid visualization of registered and processed point clouds, as well as 3D GIS model simulation and browsing. Query management includes three-dimensional GIS display of safety distance fault information, three-dimensional GIS display of visible fault information and three-dimensional GIS display of infrared fault information. See table 2 for fault contents.

| Operation name          | Name Description                                      |
|-------------------------|-------------------------------------------------------|
| Fault information import| File import                                          |
| Fault table list        | Displays a list of table contents                     |
| Import and display      | Annotation fault in 3D scene                          |
| Quick query             | Fast query by tower number, time and fault type       |
| Interactive query       | Double click the fault point warning symbol to obtain its detailed fault information |

The original inspection data of transmission line UAV includes visible light shadow image, infrared video, laser point cloud and visible light video data, as well as positioning and attitude determination data. This paper adopts the document management mode (as shown in the figure 3), and the project documents record the root directory and patrol information of the project.
2.3. Realization of data visualization in transmission line inspection

In order to obtain more accurate positioning results of inspection robot, SLAM algorithm is used to construct positioning map. SLAM algorithm is considered by many scholars as the key to truly realize the fully autonomous mobile robot because of its important theoretical and application value. Therefore, this paper uses SLAM algorithm to realize the inspection and positioning of substation robot. The robot pose information and map information are evaluated and calculated by slam technology, which can make the information close to the real situation. At time \( t \), the posture of the substation inspection robot can be described by \( \mathbf{W}_t = \{ \mathbf{W}_1, \mathbf{W}_2, \ldots, \mathbf{W}_t \} \). \( \mathbf{W}_i \) is the coordinate relative to the previous motion position. Let the robot move in an environment without considering the height, robot position \((x, y)\) and robot angle \( \alpha \). The pose \( \mathbf{w}_t \) of the robot is formed. It is assumed that there are \( n \) fixed road markings in this environment, and these road markings are used \( \alpha_j(j=1, 2, \ldots, N) \) represents the set of road punctuation points \( \alpha' \) express, \( \alpha' = \{ \alpha_1, \alpha_2, \ldots, \alpha_N \} \). The probability function of the robot's control information and the previous pose is the probability law that the robot's pose needs to follow. Want to get the robot at a fixed time \( \Delta t \) is the position information in \( t \) needs to describe the pose model of the robot. The pose vector \( \mathbf{W}_i \) of the inspection robot at time \( t \) is shown in the formula:

\[
\mathbf{W}_i = \mathbf{W}_{i-1} + \Delta \mathbf{W} + \Theta
\]  \( (1) \)

Where: \( \mathbf{W}_{i-1} \) is the pose vector at time \((t-1)\); \( \Delta \mathbf{W} \) is the change of two pose vectors; \( \Theta \) is interference noise. The position of the robot at time \( t \) can be expressed as \((x_t, y_t)\). In order to obtain the change of robot position and angle, it needs to be realized by encoder. After calculating the pose of the inspection robot, the motion model of the inspection robot can be constructed. To get the robot at the specified time \( \Delta t \) is the motion information in \( T \), the motion model of the robot needs to be defined as follows:

\[
\begin{bmatrix}
\Delta x \\
\Delta y \\
\Delta \alpha
\end{bmatrix} =
\begin{bmatrix}
\nu \cos \alpha \Delta t \\
\nu \sin \alpha \Delta t \\
\Delta \alpha
\end{bmatrix}
\]  \( (2) \)

The robot is at the specified time \( \Delta \alpha \) lateral and longitudinal displacement increments are available \( \Delta x \) and \( \Delta y \) means that the displacement increment can be regarded as time \( \Delta t \) is the reflection of the internal velocity \( \nu \) on the transverse and longitudinal coordinate axes. Speed \( V \) and angle variation \( \Delta \alpha \) it needs to be obtained through the encoder, which is installed in the left and right wheels of the robot. According to the established motion model and the obtained robot pose, the positioning formula of the inspection robot can be obtained as follows:

\[
\lambda = \frac{L \Delta \alpha}{M_N + d^i}
\]  \( (3) \)

Where: \( \lambda \) is the displacement change of the robot based on the original position; \( L \) is the length of robot motion path; \( M_N \) is the coordinates of the measuring points of \( N \) road signs; \( v_t \) is the motion speed of the robot at time \( t \); \( d \) is the length of the robot itself. The calculation function of the map based on the robot patrol positioning equation is:

\[
\delta_i = \frac{1}{M_N + d} - \frac{v_t}{(M_N + d)^2}
\]  \( (4) \)

Where: \( \delta_i \) is the moving distance relative to the original position. In order to ensure that the robot can avoid roadblocks, travel the shortest and reach the destination accurately during patrol inspection, it is necessary to plan the path. According to the equation, the robot motion path length \( Q_i \) is:

\[
Q_i = |s_i - k| + \sum_{i=1}^{n-1} |p - s_i|
\]  \( (5) \)
According to the obtained robot motion path length, the mathematical constraint equation of robot motion anti-collision is established.

\[
\begin{align*}
F(Q_t) &= 0 \\
\min Q &= \min Q_t 
\end{align*}
\] (6)

Where: \(F(Q_t)\) is the collision constraint condition, which represents the probability of collision between the path and the robot; \(\min Q\) is the shortest path. The visual collaborative management of multi-scale and multi-source spatial data related to the transmission line corridor, infrared and image of line inspection is helpful to monitor and analyze the transmission line and improve the management level of transmission line. It is an effective way for transmission line management to move towards smart grid construction.

3. Analysis of experimental results

In order to verify the application value of the substation visual inspection autonomous positioning method proposed in this paper, the accuracy of the positioning method needs to be tested. Taking a city substation as the research area, the robot is placed in the research area, and the positioning accuracy of the robot reaches the centimeter level by using the positioning method in this paper. The positioning accuracy and stability of the positioning method in this paper are verified by the following experiments. The robot collects static positioning data at 12 points of the substation, and sets the acquisition frequency as 8Hz. During patrol inspection, the robot stays at each test point for 1.5 ~ 2.5min, and the collected data are displayed in the data module of the robot. After the test, Excel and MATLAB software are used to process the collected static positioning data. In addition to collecting environmental data, the robot can also obtain the longitude and latitude information under the geocentric coordinate system, convert the information into the rectangular coordinate value under the coordinate system, and then extract the horizontal and vertical coordinate values of 180 data points to obtain the mean and standard deviation of the horizontal coordinate and the mean and standard deviation of the vertical coordinate respectively, which can be expressed as follows:

\[
\begin{align*}
\bar{x} &= \frac{1}{n} \sum_{i=1}^{n} x_i \\
s &= \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} 
\end{align*}
\] (7)

Where: \(x\) and \(s\) are the mean and standard deviation of abscissa data respectively; \(x_i\) is the abscissa of the data point. The mean and standard deviation of the data at 12 points are obtained according to the solution of equation (10). Taking the data mean and standard deviation results at position 10 as an example, the table shows the abscissa and ordinate data processing results at position 10.

| Table 3 Processing results of abscissa and ordinate data |
|----------------------------------|-------|-------|
| Mean X / M                       | 0.454 | 0.0039 |
| Standard deviation s / M         | 0.754 | 0.0038 |

When the robot passes through these 10 points during patrol inspection, the coordinate data of 10 points are collected, and the linear distance between points is obtained through the coordinate data. The figure shows the data curve in the abscissa and ordinate directions of the No. 10 measuring point.
Fig. 3 Visual inspection results of transmission line patrol inspection path

It can be seen from the fluctuation of the curve in the figure that the fluctuation amplitude of the positioning data collected by the robot is significantly lower than that of the traditional system. To a certain extent, it can be considered that the single point positioning data is relatively stable. From the distribution state of the data points, it can be seen that the autonomous positioning accuracy realized by the positioning method in this paper is very high and can be maintained within the stable level range, so as to better ensure the inspection effect and improve the data visualization quality.

4. Conclusions

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