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A collaborative management approach to transmission line forest clearing tasks in the context of grid intelligence transformation

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SUMMARY: *Tree barriers are the key factors of current transmission line failures, early discovery of tree barriers hidden dangers, the implementation of forest clearing tasks on transmission lines is the current power inspectors need to pay attention to the key issues. The article is based on the inclined photogrammetry technology to obtain the three-dimensional data of transmission lines, and construct a real-time database to realize the standardized management of three-dimensional data. Then the Mean Shift algorithm is used to preprocess the remote sensing data, and the forest diameter measurement system and transmission line forest clearing program are designed. QDN Power Supply Bureau was selected as a research sample to verify the effectiveness of the application of the above methods. The study showed that the RMSE of the breast diameter monitoring results ranged from 4.30% to 5.05%, and the reduction of forced outage rate of transmission lines of 110kV and above in the power grid could be up to 72.28%, and the overall work efficiency was improved by about 5.14 times. Therefore, actively realizing the optimization of transmission line forest clearing tasks can ensure the stable operation of transmission lines and provide basic support for ensuring the power supply of the grid.*

KEYWORDS: *inclined photogrammetry technology; real-time database; Mean Shift algorithm; breast diameter measurement system; forest clearing program*

1 Introduction

With the process of modernization, the importance of power lines has become more and more prominent. However, affected by the operating environment of transmission lines, forest trees become an important factor hindering the safe operation of lines [1]. After entering the summer or rainy season trees will be in the accelerated growth phase, the increase in tree height, branch extension, broken branches dumping and other issues will lead to transmission lines were damaged, which in turn triggered line tripping, conductive, disconnected blackouts and other power failures causing serious safety hazards [2-5]. Literature [6] examined the effect of forest trees on the distribution of electric field near overhead transmission lines, and the experimental results emphasized that with the expansion of forest growth, the electric field strength of transmission lines will be significantly reduced. Literature [7] pointed out that forest obstacles pose a serious threat to the safe operation of power transmission lines, in this regard, the typical tree species in the transmission line corridors in the Guangdong region were investigated, and

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the necessity of taking measures to ensure the safe operation of power transmission lines was emphasized. Literature [8] describes the hazards of forest risks, especially the risk of falling trees under the action of extreme winds, to the power distribution system, and concludes that these risks are prone to cause power interruptions, which can lead to serious economic losses, disruptions to daily life, and so on. Literature [9] discussed the effect of forest trees on the electric field of UHV transmission lines, and based on the number and distribution of trees, three-dimensional simulation calculations were carried out to calculate the IF electric field of the transmission lines, and the results showed that the strength of the electric field below the edges of the wires decreased with the increase of the number of trees. Literature [10] identified forest fires as one of the factors affecting the safe operation of transmission lines and concluded that the flammability of forest trees causes frequent forest fires, which in turn tends to cause the deterioration of transmission lines and threatens the safety of power grids. The above studies specify the hazards that forest factors may cause to transmission lines. Therefore, forest clearing has become an important task.

Through the establishment of a regular inspection mechanism, the hidden safety problems can be found early and removed in time, however, the traditional manual line inspection method has a series of problems at the level of work intensity, work efficiency, and safety index, which cannot guarantee the safe operation of the power grid [11-13]. And under the intelligent transformation of the power grid, the automation and intelligence of forest clearing is realized through the use of advanced technical means, which further improves the transmission line operation guarantee [14, 15]. Grid intelligent transformation is a profound change in the energy field, the core of which lies in the deep integration of the traditional power system with modern information technology to cope with the increasingly complex energy demand and environmental challenges. At the same time, the wide application of intelligent devices makes the control and management of power systems more refined [16-19].

Regarding the importance of digital transformation in the electric power industry, literature [20] points out that due to the surge in power demand, electric power enterprises are facing severe challenges demand, and emphasizes the important role played by digital transformation in improving the management and service level of electric power enterprises, and suggests that power grid enterprises comply with the trend of digital development, and actively implement digital transformation. Literature [21] analyzes the digital transformation of power grids based on artificial intelligence technology and discusses in depth the economy, quality and coordination of power grid development, and the results point out that digital transformation can effectively promote the overall development of power grids. Literature [22] elaborated that AI technology improves the efficiency of grid operation, enhances the intelligence and reliability of the grid, and emphasizes the importance of the digital transformation of the grid in improving the efficiency of energy supply, optimizing the allocation of resources, and ensuring energy security. Literature [23] identified the core driving mechanism and key technological paths by analyzing the comprehensive framework of digital transformation of power grid enterprises, and pointed out that the introduction of smart technology systems in the process of digital transformation has significant benefits for power grid enterprises.

Intelligent equipment such as drones and remote sensing monitoring can be utilized in the task of forest clearing on transmission lines by coordinating departments such as electric power, forestry, and emergency management [24]. This collaborative management method improves the quality and efficiency of the forest clearing task, thus guaranteeing the reliability of line operation [25]. At the same time, the staff can view and timely check the working status of the line and equipment in real time at the terminal, and realize intelligent early warning through the intelligent platform to provide the best cleanup advice, which guarantees the safety of the power staff and the safety of the power grid to a certain extent, and is conducive to the scientific and efficient management of the power grid and improving the ability to deal with unexpected fault events [26-29]. Literature [30] describes the risks posed by forest trees to power transmission lines, and proposes a method for detecting and managing the distance between forest trees and power lines with machine learning technology, and the results show that the monitoring method of artificial intelligence strengthens the potential in terms of forest management strategies and reduces the associated risk of power outages. Literature [31] describes a method for remote clearing of forest trees based on laser obstacle removal technology, points out the shortcomings of the method, and proposes a system fused with video- and image-based artificial intelligence technology to realize real-time fault judgment and automatic clearing, which solves the efficiency problems caused by human misjudgment in power transmission lines. Literature [32] describes that the intrusion of forest trees into transmission lines may lead to short-circuit failures and threaten the safety and stability of the power grid, based on which a transmission line fault detection system based on visual detection algorithms is proposed, which improves the overall reliability and reduces economic losses.

In order to make up for the shortcomings of existing research, this study designs a transmission line forest clearing scheme from the dimensions of data collection, data management, feature measurement, and example analysis, aiming to improve the efficiency of operation and maintenance personnel and enhance the operational stability of transmission lines. This study provides a new research basis for the collaborative management of transmission line forest clearing tasks, and provides an auxiliary solution for promoting the intelligent transformation of power grids.

2 Forest characterization data collection and measurement design

Electricity is one of the main sources of energy required for industrial production and national life, and the demand for electric energy is enormous. The state invested a lot of financial resources to build the power grid facilities, not only widely distributed, across the region, and is located in a very complex environment, so the safe operation and maintenance of the power grid is very important. Regularly clean up the transmission lines in the forest obstacles belong to the grid operation and maintenance of an important work, especially in the hilly or mountainous areas, the forest cleanup has become the main work of the grid operation and maintenance personnel must face the main difficulties and pain points.

2.1 Real-time data collection techniques and processes

2.1.1 Tilt photogrammetry

In order to ensure the safe and stable operation of transmission lines, it is necessary to strengthen the three-dimensional and all-round control of transmission line channels. At present, there are certain hidden dangers in the transmission line corridor, such as super-high vehicles touching the line hidden dangers, forest obstacles and so on. Transmission line operating environment is becoming more and more complex, two-dimensional map has been unable to meet the line corridor corridor control needs. For this reason, it is required to create a three-dimensional visualization model of the transmission line, which will fully show the real appearance of the transmission line.

UAV tilt photogrammetry technology breaks the limitation that traditional UAV aerial photogrammetry is only able to shoot the surface features through a separate high-resolution camera based on the vertical angle, and utilizes the loading of multiple high-resolution cameras and sensors in the same UAV flight platform. At the same time, image shooting can be realized through different angles, such as side view, vertical, front and back, which can get accurate and complete feature information on the ground surface. For orthophoto images, tilt photography can reflect the surface three-dimensional environment completely and truly. Through the operation of professional computer software, the use of air three encrypted measurements to obtain three-dimensional stereo image, the use of image matching can generate three-dimensional scene. Through the 3D model reconstruction technology to realize the generation of visual stereo 3D model, and realize the length, height, volume, area, slope, angle and other attributes of the results of the image measurement.

2.1.2 Real-time data acquisition process

The UAV tilt photography technology in the forest task clearing and detection of transmission lines under electric power patrol refers to the use of fixed-wing or multi-rotor UAVs as the flight platform, equipped with high-precision positioning devices and imaging systems, to obtain the optical images of the forest data of transmission lines, and to utilize the principle of photogrammetry to recover the three-dimensional scene of the transmission lines with high-precision coordinates, so as to identify and locate the targets of forest obstacles within the transmission lines. Figure 1 shows the working principle and specific process of UAV tilt photography technology in power patrol line forest task clearance detection.

Firstly, aerial photography of the transmission line is carried out, and then the raw data such as images and flight POS parameters acquired by the UAV are processed using aerial triangulation methods to solve the absolute orientation parameters of the images. Then the surface and conductor of the transmission line are reconstructed in three dimensions respectively, and finally, based on the three-dimensional reconstruction results of the surface and conductor of the transmission line, obstacles (forest obstacle barriers, house barriers, and cross-crossing) are detected by calculating the spatial distances between the power line and the point cloud on the surface. And using the measured three-dimensional coordinates of the conductor and the coordinates of the hook-up points of the two ends of the conductor on the pole tower, the data results are calculated and output.

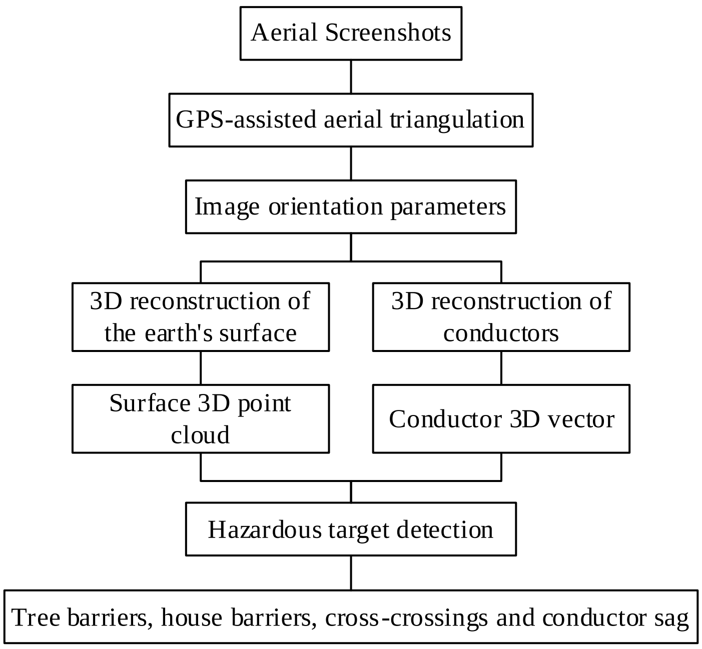

Figure 1: Real-time data acquisition process

2.2 Establishment and management of real-time databases

2.2.1 Establishment of a real-time database

The technical route of the transmission line forest clearing database is the basic premise of the implementation of the building database, the establishment of the forest clearing database requires different stages of orthophoto maps, vectorization of all channel clearing objects. And endowed with the required attribute fields, through the operation of the attributes to realize the analysis and retrieval of data, such a database can be convenient to query the location of the forest clearing object and other related attributes, highlighting the practicality of the database.

Transmission line forest clearing data mainly includes graphic and attribute data by category, basic geographic information data including provincial, municipal and county boundaries, major road networks, large-scale water systems, etc., and channel image data including mainly Guardian images, images of the design stage of the research and development, and so on. Clearance data mainly include house demolition and relocation data, forest demolition and relocation data, plant industrial and mining demolition and relocation, and tower occupation data, etc. Engineering design data mainly include line coordinates, package section marking and so on. Other related data mainly include photos before, during and after house demolition and relocation, photos of forest before felling, after felling and site restoration, agreement documents at each stage, related government documents, etc. Figure 2 shows the database establishment process based on ArcGIS.

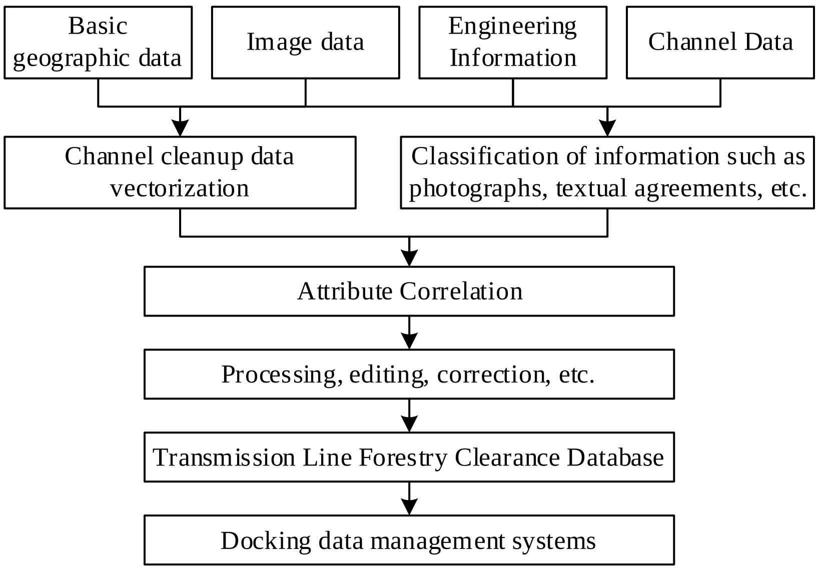

Figure 2: Database establishment process based on ArcGIS

2.2.2 Standardized management of real-time data

The operation network of the transmission line channel visualization system is based on LAN, and there are two kinds of servers: data server and application server. Electric power enterprises can adopt the integrated server based on the actual demand, and the integrated server integrates the functions of data and application servers. Its specific functions are as follows:

(1) Three-dimensional data acquisition and storage. The system can collect three-dimensional data, such as forest data, building data and power line data, through LiDAR and store them in the spatial database.

(2) Three-dimensional data management. The system can manage the collected 3D data and

provide various operations, such as rotating, flying and roaming.

(3) Convenient query service. The staff can log in the ledger system and query the information they need, such as the voltage level of the transmission line, the length of the line, and the distribution of forests.

(4) Data interaction. Staff can maintain and manage on-plane lines and forest trees with the help of GIS system.

(5) Statistics and management of spans. The airborne measurement system can reach the purpose of counting and managing crossing objects when flying.

(6) Simulation function. Staff can use the ledger system to simulate damage to transmission lines in the event of a natural disaster.

(7) Data management. The data management mentioned here mainly refers to the management of line operation and maintenance data, and through the parameter setting, the system will issue an alarm when the line is faulty, reminding the staff to overhaul the circuit.

2.3 Forest Characterization Measurement and Clearance Programs

2.3.1 Preprocessing of remote sensing data

On the basis of image data acquisition using a UAV and a laser scanning sensor, the remote sensing spectra acquired by the optical sensor are subjected to corner detection. In the active contour wave domain, the laser spectral energy driving function of the remote sensing image is obtained as:

$$V_c(x) = \beta\left(1-\delta\left(x_i, x_j\right)\right) \tag{1}$$

In the formula, β is the local active contour model, Harris corner point detection method is adopted, the remote sensing image collected by UAV LIDAR is processed by adaptive filtering and image electronic image stabilization, the corner point information is extracted, and the two-dimensional adaptive weighting of the image is realized, and the impulse response function δ function is constructed as:

$$\delta\left(x_i, x_j\right) = \begin{cases} 1 & x_i = x_j \\ 0 & other \end{cases} \tag{2}$$

In the gradient distribution region of the image, the acquired laser remote sensing gray scale image $I(x, y)$ is divided into two regions R_1 and R_2 according to the contour curve C, and then the differential pixel level difference function of the target region and the background region for remote sensing region detection of the ground target is denoted as:

$$E_g = \sum_{i=0}^{L-1} r_i p\left(r_i\right) \tag{3}$$

The level set of pixels is initialized to obtain the target histogram of the image as:

$$\sigma_g^2 = \sum_{i=0}^{L-1} \left(r_i - E_g\right)^2 p\left(r_i\right) \tag{4}$$

It is assumed that during the UAV LIDAR acquisition process, in the $M \times M$ image imaging region centered on the laser sensor node $Q(i, j)$, the remote sensing mapping feature detection basis function expression is:

$$c\left(x, y;\sigma,\lambda,\theta_k\right) = \exp\left\{-\frac{1}{2}\left[\frac{\left(x-\mu_x\right)^2}{\lambda\sigma^2}\right]+\frac{\left(y-\mu_y\right)^2}{\lambda\sigma^2}\right\} \cdot \exp\left[\frac{2\pi\left(x\cos\left(\theta_k\right)\right)+y\sin\left(\theta_k\right)}{\lambda}\right] \tag{5}$$

where λ is the region mask parameter, μ_x and μ_y are the 3D reconstruction center position covariates of the remote sensing imaging, σ^2 is the integral histogram of the current frame image, and θ_k is the fluctuation orientation information.

Through the Mean Shift algorithm for corner detection of remote sensing mapping, the similarity of the corner distribution of remote sensing images is obtained in the neighborhood with the primitive vector as the reference center:

$$D = \sum_{v}\left\|g\left(x, y;\sigma,\lambda,\theta_k\right)-g'\left(x, y;\sigma,\lambda,\theta_k\right)\right\| \tag{6}$$

where $g\left(x, y;\sigma,\lambda,\theta_k\right)$ and $g'\left(x, y;\sigma,\lambda,\theta_k\right)$ are the statistical histograms and the intraclass discretization information, respectively, and in the case of neighboring primitive vectors In the presence of affine invariant moments, the remote sensing map detection is realized by the similarity measure, and the model expression of the output map likelihood function is obtained as:

$$V_c\left(x_i, x_j\right) = \begin{cases} 0 & x_i = x_j \\ \left(1-e^{-\alpha D}\right) & other \end{cases} \tag{7}$$

A multiscale mapping segmentation method with graph likelihood function is used for image pixel feature point clustering and remote sensing image reconstruction in specific gray scale intervals.

2.3.2 Forest tree diameter measurement methods

The chest diameter measurement value of the forest tree chest diameter continuous measurement equipment is determined by the length of the synchronous belt in the chest diameter measurement, i.e., the chest diameter sensor outputs different voltage signal values through the different lengths of the synchronous belt stretching, the principle of the chest diameter sensor designed in this study is shown in Fig. 3 (in the figure, 1, 2 and 3 represent the pins, and RP represents the adjustable resistor).

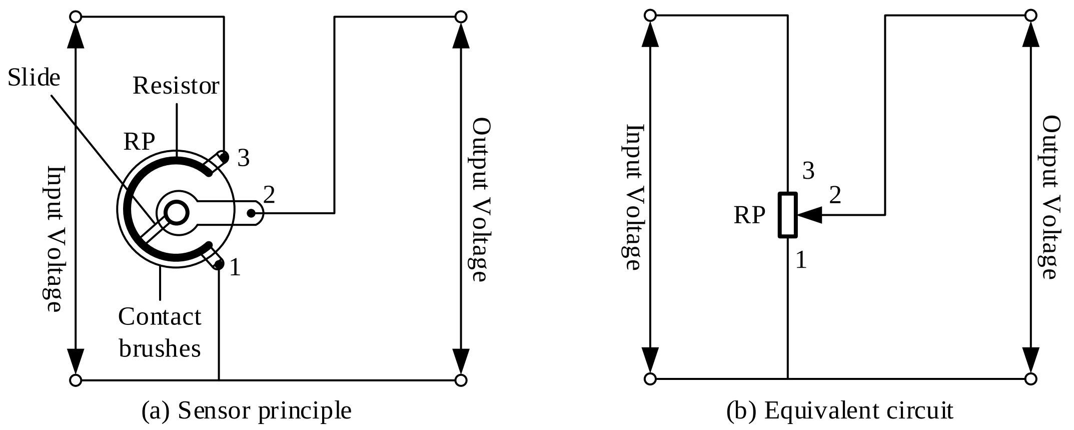

Figure 3: Principle of the diameter at breast height sensor

The diameter measurement system consists of a housing, a synchronous belt, a synchronous pulley and a high-precision displacement sensor installed inside the housing. During tree diameter measurement, the timing belt is stretched outward and drives the timing belt pulley to rotate, and the sensor spindle is driven by the central axis to rotate during tree growth. The sliding contact is in contact with the resistor body and moves to change the resistance value, and the amount of change in the length of the toothed belt corresponds to the diameter of the tree's chest. Using a high precision displacement sensor, the resistance variable can be converted into a voltage variable, and the Arduino chip reads the voltage change value and calculates it, so as to obtain the actual measurement value of the diameter of the chest.

The relationship between the diameter of breast diameter (D) and the length of toothed belt (L) is:

$$D = \frac{L}{\pi} \tag{8}$$

The relationship between the length of the toothed belt (L) and the amount of resistance change (R_i) is:

$$L = R_i A + B \tag{9}$$

where A is the device resistance coefficient and B is the experimental coefficient.

The resistance change (R_i) is related to the measured change voltage as:

$$R_i = \frac{V_0 R - V_1 R}{V} \tag{10}$$

where, V_0 the initial voltage when not measured, V_1 the voltage at the time of measurement, V the voltage of the power supply, and R the maximum resistance of the sliding resistor.

From Eq. (8)-Eq. (10), the relationship between the diameter of the chest (D) and the voltage (V_1) at the time of measurement can be deduced as:

$$D = \frac{A(V_0 R - V_1 R)}{V\pi} + B \tag{11}$$

Since V_0, R, V, A in Eq. (11) are all constants, Eq. (11) can be simplified as:

$$D = K\left(V_0 - V_1\right) + B \tag{12}$$

where $\mathbf{K}$ is the experimental coefficient, which can be obtained by multiple realizations.

From equation (12), it can be seen that the voltage (V_1) is linearly correlated with the chest diameter (D) during measurement.

In order to ensure high-precision diameter measurement, the measuring device is based on the principle of sensor displacement measurement, combined with the synchronous belt drive structure, to build an effective method of converting changes in tree diameter into voltage changes. Through the structural design of the toothed belt engaging with the precision timing belt pulley, it ensures that the outlet of the toothed belt always remains parallel when it is stretched, which significantly improves the linear correspondence between the stretched length and the rotation angle of the central axis, and thus improves the measurement accuracy and stability of the whole system. On this basis, combined with the functional relationship between resistance change and voltage sampling, the mathematical model between the diameter of the breast diameter and the measured voltage is deduced to realize the continuous and high-precision monitoring of the diameter of the tree breast diameter.

2.3.3 Forest feature extraction process

The combination of 3D laser scanning system and breast diameter measurement system is used to construct the flow chart of extracting forest features of transmission lines as shown in Fig. 4, which mainly includes the steps of data acquisition, point cloud preprocessing, forest feature extraction, data analysis and validation.

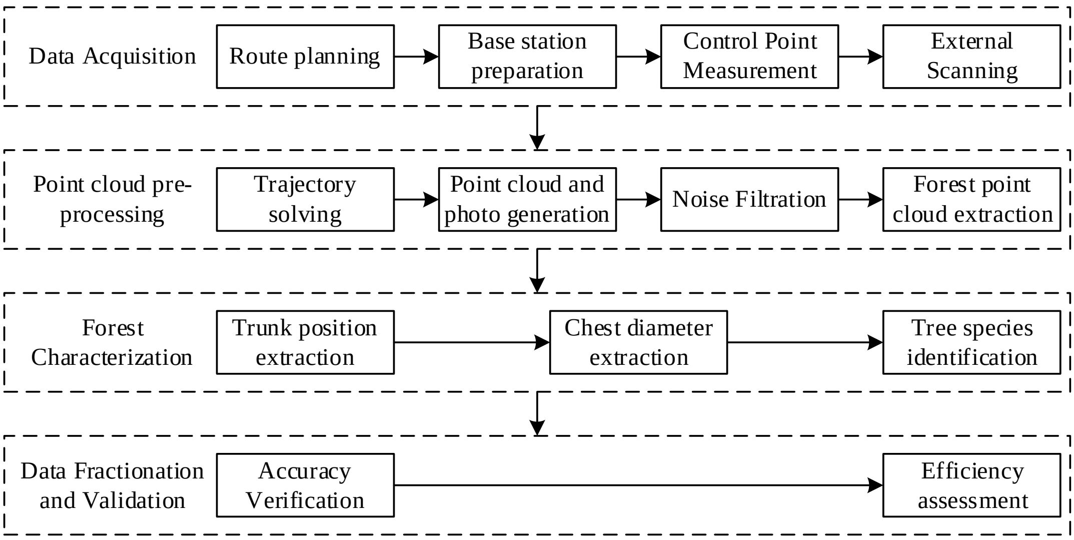

Figure 4: Forest tree feature extraction process

(1) Data acquisition. Make the path planning in advance, complete the base station and control point measurement, then, use the mobile 3D laser scanner to scan the forest area and obtain the high-density point cloud data.

(2) Point cloud preprocessing. Based on the base station and mobile station data to solve the scanning trajectory, generate the point cloud and panoramic photo, denoise the point cloud,

through the cluster analysis and morphological processing, and finally get the forest tree point cloud.

(3) Forest tree feature extraction. Based on the point cloud, we extracted forest features including location, diameter at breast height (DBH) and tree species, and further improved the monitoring results of DBH by combining with the DBH measurement system.

(4) Data analysis and validation. Compare the extracted tree features with the field measurement data to assess the accuracy of the method. The efficiency and cost of different methods are also compared.

2.3.4 Forest Clearance Program Design

In this paper, the width of line corridor tree clearing is calculated from the transmission line conductor at rest and under wind deflection respectively, while considering the two cases of tree not falling and falling. The wind deflection of the line below the value of the middle deflection angle (less than 10°) is approximated to be stationary, and set the arc droop of the conductor at rest to be f_j, the distance to the ground of the conductor at rest to be S_g, and the maximal wind deflection angle of the conductor to be θ_w; if the insulators of the transmission line conductor are I strings, then f_j is the sum of the actual line arc sag and insulator string length, and if the insulator of the conductor line is a V string, then f_j is the actual arc sag of the line; the actual arc sag is obtained by the separated laser point cloud data, and the length of the insulator string is the design value.

(1) Tree cutting width when the conductor is stationary. When considering the case of trees not dumping, the felling width D_1 is calculated as:

$$\begin{cases} D_1 = S_{jk} & , H_n \geqslant S_g \\ D_1 = \sqrt{S_{jk}^2 - \left(S_g - H_n\right)^2} & , H_n < S_g \end{cases} \tag{13}$$

where S_{jk} is the minimum clearance distance between the conductor and the tree when it is stationary; H_n is the natural growth height of the tree.

When tree dumping is considered, the felling width D_2 is calculated as:

$$\begin{cases} D_2 = \sqrt{\left(H_n + S_{jj}\right)^2 - S_g^2} & , H_n + S_{jj} \geqslant S_g \\ D_2 = 0 & , H_n + S_{jj} < S_g \end{cases} \tag{14}$$

where S_{jj} is the minimum clear distance between the conductor and the fallen tree during tree dumping. The final felling width when the wire is stationary is taken as $D_j = \max\left(D_1, D_2\right)$.

(2) Tree cutting width at maximum wind deflection. The horizontal offset p_h and vertical offset p_v of the conductor at maximum wind deflection are:

$$\begin{cases} p_h = f_j \cdot \sin\theta_w \\ p_v = f_j \cdot \left(1 - \cos\theta_w\right) \end{cases} \tag{15}$$

The felling width D_3 is calculated when considering the case where the tree is not dumped:

$$\begin{cases} D_3 = S_{jw} + p_h & ,H_n \geqslant S_g + p_v \\ D_3 = \sqrt{S_{jw}^2 - \left(S_g + p_v - H_n\right)^2} + p_h & ,H_n < S_g + p_v \end{cases} \tag{16}$$

where S_{jw} the minimum clearance distance between the conductor and the tree when the conductor has maximum wind deviation. When the tree dumping situation is considered, the felling width D_4 is calculated as:

$$\begin{cases} D_4 = \sqrt{\left(H_n + S_{jw}\right)^2 - \left(S_g + p_v\right)^2} & ,H_n + S_{jw} \geqslant S_g + p_v \\ D_4 = 0 & ,H_n + S_{jw} < S_g + p_v \end{cases} \tag{17}$$

The final tree felling width at maximum wind deflection is taken as $D_w = \max\left(D_3, D_4\right)$.

3 Application performance of transmission line forest clearing

Transmission line distribution points, wide, and many lines are located in the wilderness, complex terrain, the need for regular inspection and maintenance in order to protect the safety of transmission line operation. In recent years, transmission line inspection workload with the increase in grid size and voltage level, the rapid expansion of long-distance transmission lines and surge, the traditional manual inspection has been difficult to meet the transmission line inspection requirements. Therefore, further promoting the intelligent transformation of the power grid can realize the intelligent inspection of transmission lines, improve the efficiency of forest clearing tasks, and better ensure the stable operation of transmission lines.

3.1 Effectiveness analysis of forest characterization monitoring

3.1.1 Measurement of forest barrier distances

In this paper, an actual operating same-tower double-circuit line in the area of QDN Power Supply Bureau was selected for field testing, with an ambient temperature of 20℃ and a wind speed of 5m/s. The line was tested in the area of QDN Power Supply Bureau. A multi-rotor UAV equipped with 3D LIDAR was used for flight inspection, and 3D LIDAR transmission line forest obstacle inspection experiments were carried out in gears #30-#31, #31-#32, #32-#33, #33-#34, and #42-#43, respectively. In order to ensure the safety of the aircraft and the conductor, the horizontal distance between the aircraft and the conductor is set to be 6 m. In the inspection regulations, the safety distance of the forest obstacle offline is 8 m away, and this experiment sets the offline distance threshold of the forest obstacle to be 8.5 m. In this paper, the maximum and minimum values are set to be 2400 and 120, respectively, according to the degree of denseness of transmission lines.On the other hand, traditional means such as laser ranging telescopes are used to compare the actual measurement of forest obstacle distances and calculate the relative errors of the two, in order to validate the accuracy of the measurement method proposed in this paper. Table 1 shows the inspection report of forest barriers.

Table 1: Inspection report on forest obstacles

Index	1	2	3	4
Longitude (°)	114.3103	114.3128	114.3141	114.3169
Latitude (°)	21.3324	21.3315	21.3309	21.3301
Horizontal distance (m)	0.146	0.573	0.989	1.523
Vertical distance (m)	6.415	6.849	7.164	6.792
Clearance distance (m)	6.426	6.905	7.182	6.801
Distance from the small tower (m)	41.348	45.271	46.936	67.315

Table 2 shows the measurement results of forest obstacle distance under different measurement methods. From the comparison results of the measurement data in the table, it can be seen that the maximum relative error between the measurement method based on the UAV 3D LIDAR system proposed in this paper and the traditional measurement method using laser ranging telescope is -1.44%~1.13%, which proves that the measurement results are credible and effective. In addition, in the same transmission line inspection process, because no inspectors need to patrol the line over the mountains, the method described in this paper compared with the traditional measurement method required inspection time consuming greatly reduced, a greater increase in the transmission line forest obstacles inspection operation efficiency.

Table 2: Measurement of forest obstacle distances under different methods

Measurement position	This article (m)	Traditional method (m)	Relative error
#30-#31 (125.76m)	9.923	9.908	0.15%
#31-#32 (33.68m)	7.315	7.345	-0.41%
#32-#33 (41.52m)	4.462	4.461	0.02%
#32-#33 (46.83m)	7.135	7.146	-0.15%
#32-#33 (65.91m)	6.536	6.533	0.05%
#33-#34 (552.18m)	5.642	5.627	0.27%
#33-#34 (561.73m)	4.516	4.582	-1.44%
#33-#34 (554.46m)	4.743	4.699	0.94%
#33-#34 (547.54m)	5.397	5.356	0.77%
#33-#34 (538.92m)	0.358	0.354	1.13%
#33-#34 (606.28m)	2.142	2.161	-0.88%
#42-#53 (305.12m)	6.161	6.149	0.20%
#42-#53 (273.53m)	6.152	6.138	0.23%
#42-#53 (266.69m)	6.606	6.602	0.06%

3.1.2 Comparison of environmental resilience

Environmental adaptability includes the ability of the UAV to adapt to the low-temperature environment, high-temperature environment, altitude environment, outdoor environment, and rainy environment when inspecting transmission lines. In this study, the altitude environment is simulated, and the artificial laboratory is used to simulate the altitude environment, and the traditional inspection technology and the UAV inspection technology of this study are selected to inspect the transmission lines at the same time, and the experimental results obtained from the inspection are shown in Table 3.

Based on the data in the table, the following conclusions are obtained:

(1) The traditional method can adapt to the ambient temperature of -15~25℃, while the method in this paper can adapt to the ambient temperature of -25~45℃.

(2) In the simulation of high-altitude environment, the traditional method can break through the highest altitude of 1200m, while this method can break through the highest altitude of 2400m.

(3) When the instantaneous wind speed reaches 8m/s, it is difficult for the traditional inspection technology to ensure normal work, but the inspection technology in this study can still work normally, and the horizontal deviation displacement and vertical deviation displacement from the hovering point when the UAV is hovering are less than 0.82m and 1.05m respectively.

(4) When there is light rain, the transmission line inspection UAV can still maintain normal flight, the flight speed is as low as 4m/s, and it is difficult to maintain normal flight for the UAVs used in traditional inspection technology.

Table 3: Environmental adaptability test results

Index	Traditional method	This article
Adapt to the ambient temperature (℃)	-15~25℃	-25~45℃
Break through the highest altitude (m)	1200m	2400m
Light Rain environment	Unable to fly normally	Can fly normally
Horizontal deviation displacement (m)	1.48m	0.82m
Vertical deviation displacement (m)	0.86m	1.05m

3.1.3 Effectiveness of monitoring of forest characteristics

From the results of monitoring efficiency of transmission line forest resources, by comparing the monitoring efficiency of using UAV LIDAR with the manual monitoring efficiency, it took a total of 45 min for UAV to monitor the scope of the study area, and the difference was highly significant (P<0.01) compared with the efficiency of manual survey. It indicates that compared with the traditional manual operation survey, when using UAV LIDAR to carry out the transmission line forest monitoring task, it is able to realize automated identification and monitoring records, and its operational efficiency has significant advantages.

From the results of monitoring data quality assessment, the study carried out automatic identification of different tree species by UAV LIDAR, taking the ratio of the number of correctly detected trees to the total number of reference trees as the main assessment index, and verified it in combination with the real parameters of the trees obtained from the manual field survey. The recognition accuracies of the tree species are relatively close to each other, mainly including three types of eucalyptus, horsetail pine and fir.

In this study, UAV LiDAR was used for automatic monitoring, and the forest growth parameters were calculated based on the constructed algorithmic model. By comparing the differences between the UAV LiDAR monitoring and manual determination results and the real values, the average diameter at breast height (DBH), tree height and volume of lumber of Masson pine, Eucalyptus and Fir were analyzed, and the comparative results of the monitoring of forest characteristics are shown in Table 4. The comparison results of forest characteristics monitoring are shown in Table 4. The RMSE was also used as the evaluation index of monitoring accuracy, and the comparison results were obtained as shown in Table 5.

The results in Table 4 show that the average error of the forest characteristics data automatically monitored by UAV LIDAR is significantly lower than that of manual determination (P<0.01), which verifies the effectiveness and reliability of UAV LIDAR technology in the monitoring of forest characteristics indicators. As can be seen from Table 5, the RMSE of the results of automatic monitoring of diameter at breast height, tree height and volume of wood using UAV LiDAR were 4.30%~5.05%, 1.43%~1.75% and 13.33%~17.86%, respectively, which showed extremely significant differences (P<0.01) compared with the results of manual measurement. It proved that the automatic monitoring of forest growth results using UAV LiDAR has high accuracy and good data quality.

Table 4: Forest characteristics monitoring comparison results

Tree species	Index	Truth	Ours	Manual	*t*	*P*
Masson pine	Chest diameter/cm	18.31	18.34	18.02	6.247	0.000
	Tree height/m	10.43	10.41	9.81	-4.152	0.003
	Material volume/m^3	0.26	0.26	0.26	3.783	0.004
Eucalyptus	Chest diameter/cm	11.84	11.85	12.24	5.206	0.000
	Tree height/m	14.79	14.81	15.68	3.278	0.002
	Material volume/m^3	0.15	0.15	0.15	4.364	0.001
Fir wood	Chest diameter/cm	20.99	20.97	19.79	-5.415	0.007
	Tree height/m	12.83	12.86	12.27	4.689	0.005
	Material volume/m^3	0.28	0.28	0.26	3.753	0.000

Table 5: Accuracy comparison results

Tree species	Index	RMSE			
		Ours	Manual	*t*	*P*
Masson pine	Chest diameter/cm	0.86	1.13	-9.128	0.000
	Tree height/m	0.15	0.45	-6.751	0.000
	Material volume/m^3	0.04	0.06	-2.173	0.005
Eucalyptus	Chest diameter/cm	0.51	0.74	-3.654	0.002
	Tree height/m	0.26	0.68	-7.516	0.001
	Material volume/m^3	0.02	0.04	-3.273	0.000
Fir wood	Chest diameter/cm	1.06	1.53	-5.303	0.007
	Tree height/m	0.21	0.76	-4.264	0.002
	Material volume/m^3	0.05	0.07	-6.751	0.005
Tree species	Index	RMSE/%			
		Ours	Manual	*t*	*P*
Masson pine	Chest diameter/cm	4.69	6.17	-4.751	0.001
	Tree height/m	1.43	4.31	-3.241	0.000
	Material volume/m^3	15.38	23.08	-8.472	0.005
Eucalyptus	Chest diameter/cm	4.30	6.25	-6.826	0.002
	Tree height/m	1.75	4.59	-5.738	0.000
	Material volume/m^3	13.33	26.67	-6.483	0.006
Fir wood	Chest diameter/cm	5.05	7.28	-5.237	0.001
	Tree height/m	1.63	5.92	-6.571	0.000
	Material volume/m^3	17.86	25.00	-9.793	0.000

3.2 Effectiveness of transmission line forest clearance

3.2.1 Reliability of transmission lines

In the context of the intelligent transformation of the power grid, QDN Power Supply Bureau always carries out tasks about transmission line forest clearing in order to commit to better ensure the stable operation of transmission lines and provide customers with stable power support. In 2019 QDN Power Supply Bureau actively carries out transmission line rate technology upgrading, on the basis of which, in 2024, it continues to optimize the technology related to transmission line rate forest clearing tasks, combining the forest clearing scheme given in the previous section, and organizing the data obtained as a way of analyzing the reliability of the transmission line rate in the context of digital transformation.

In view of the changes in the reliability of transmission lines, this paper selects the average customer outage time (medium voltage), the average customer outage time (low voltage) and the forced outage rate of transmission lines (11kV and above) as the evaluation indexes, and obtains the results of the reliability operation of transmission lines as shown in Figure 5.

As can be seen from the figure, since the digital transformation of the grid was carried out in 2019, the forced outage rate of 110kV and above transmission lines on the grid has been reduced from 0.184±0.027 outages/(100km-year) in 2019 to 0.051±0.024 outages/(100km-year) in September 2025, with an overall reduction of 72.28%, after the active implementation of the forest clearing task. In addition, the reduction in average customer outage time (low voltage) and average customer outage time (medium voltage) reached 66.35% and 63.72% respectively over the 7-year period. By strengthening the digital penetration control of transmission line forest clearing tasks, establishing accurate data ledgers, and efficiently disposing of forest obstacle hazards on-site, the transmission line-related production indicators continued to improve, the quality of operation and maintenance was significantly improved, and no grid and power-related public safety incidents triggered by fires in forested areas occurred. Digital transformation and digital transmission construction practice, for management change and total factor productivity enhancement provides a strong impetus to “command centralization, operation intensification, maintenance localization, maintenance state” as the principle, the formation of provincial intelligent operation center. Intensive transmission intelligent inspection, image recognition, data analysis and other new businesses, intelligent operation in the field of transmission “staff reduction and efficiency” obvious, transparent business management, evaluation and analysis of accurate, digital transformation results have appeared to realize the change in the management model and improve the governance capacity.

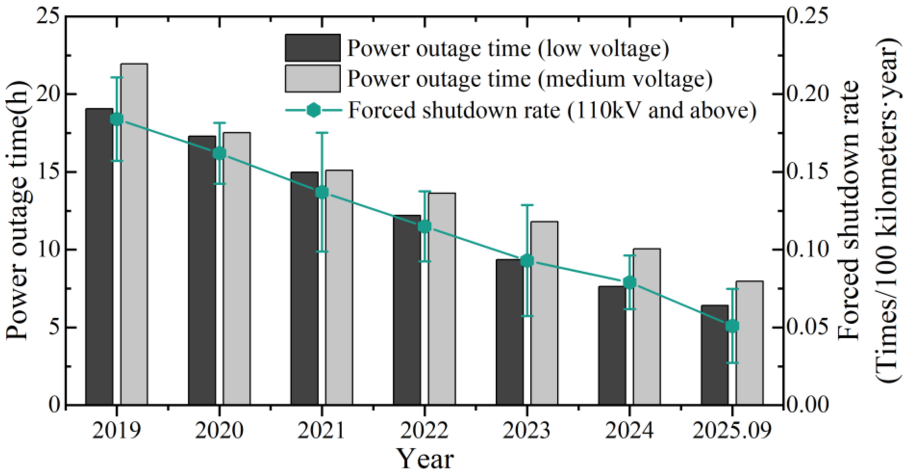

Figure 5: The reliability operation results of transmission lines

3.2.2 Comprehensive analysis of application benefits

Based on the transmission line forest clearing program designed in the previous section, it is applied to the transmission line forest clearing tasks under the area of QDN Power Supply Bureau, and it is found during the application process that it can not only be used for forest clearing of the blackout line, but also can be operated by the insulated tool to carry out the operation on the non-stop transmission line, and it can be widely used in 110kV and above transmission line conductor and conductor diameter is larger than 25mm distribution line. It can be widely used in the cleaning of foreign objects on 110kV and above transmission lines and distribution lines with conductor diameter larger than 25mm. In the application process, the comprehensive benefits are as follows:

(1) Economic benefits. After the application of the program, the average time of each transmission line forest clearing operation is reduced from the original 3 hours to the current 35min, the efficiency of the work has been improved by about 5.14 times, the forest clearing operator labor intensity has been greatly reduced, and the danger of the operation has been significantly reduced.

(2) Social benefits. The application of the transmission line rate forest clearing program has greatly improved the efficiency of forest clearing, effectively avoided the line tripping caused by foreign objects hanging on the wires, and improved the reliability of power supply. 2024 to the present, the QDN Power Supply Bureau has applied the results of the cumulative application of the results of the 28 times, clearing all kinds of forests in a total of 42 places, and the cumulative amount of power supply reaches $2.85*10^5$kW·h, and the cumulative reduction of outages of more than 12,000 households, effectively ensuring that the power supply of the power supply. This has effectively ensured the safe and reliable operation of the power grid and brought good social benefits.

Meanwhile, in the application practice of transmission line forest clearing task, the forest clearing program and insulated operating rod, laser gun and other cleaning tools with the use of the transmission line forest clearing needs to meet the vast majority of cases, effectively solving the traditional mode of operation under the forest clearing problems. The design and application of the forest clearing program also adapts to the current transmission line automation, intelligent operation development trend, and further enhance the transmission line operation and maintenance maintenance technology level.

4 Conclusion

The article is based on the tilt photogrammetry technology to obtain the three-dimensional data of transmission lines, and established the implementation database to realize the standardized management, designed the forest tree breast diameter measurement method and cleanup program, and launched the effectiveness analysis through the application. The results show that the RMSE of the results of using UAV LIDAR to monitor the breast diameter is 4.30%~5.05%, and the reduction of the forced outage rate of 110kV and above transmission lines in the power grid reaches 72.28%, and the efficiency of the work is improved by about 5.14 times. Therefore, the optimization of transmission line forest clearing tasks actively carried out under the background of grid intelligent transformation can further improve the operation and maintenance effect of transmission lines and better ensure the stable operation of the power grid.

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