Optimization of minimum crossing distance of transmission line based on multi objective ant colony algorithm

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Abstract—In the test of cross span distance of transmission line, the estimation of cross span distance is not accurate, which leads to the increase of subsequent test error. Therefore, a test method of transmission line cross span distance based on a multi-objective ant colony algorithm is proposed. Statistics of the actual information of different crossovers including trees and forest areas. Considering the transmission line as a flexible cable, the objective function for estimating the cross span distance of the transmission line is constructed according to the catenary model of the flexible cable model. On this basis, the multi-objective ant colony algorithm is used to solve the function, and the optimization results of transmission line crossing distance are output. The experimental results show that the method has high accuracy, small error, short time and reliability.

1. INTRODUCTION
With the continuous expansion of the construction scale of long-distance, large-capacity and ultra-high-voltage transmission lines, transmission corridors are becoming more and more tense, leading to the phenomenon of crossing over many overhead lines, and also causing line discharge accidents due to too small crossing distances. In order to reduce the occurrence of accidents and reduce the cost of construction, the crossing distance of transmission lines has become the most effective means to solve these problems. Therefore, in order to achieve more precise results, a cross-over distance test is required [1]. Cross-crossing distance test of transmission lines refers to the test of the intersection distance between transmission lines and other lines such as roads, railways, cableways, pipelines, power lines and communication cables. Alternatively, the distances of transmission lines through rivers, mountains, forests and buildings are tested to avoid the occurrence of flashover or interference from the electromagnetic network, resulting in safety incidents [2].

Great attention has been paid to the research of transmission line cross the over distance tests at home and abroad, and fruitful research results have been obtained. The research of transmission line cross over distance test in foreign countries focuses on the selection of measuring points and estimation of sag variation. In our country, the research on transmission line crossover distance test is relatively late, and the emphasis is put on the crossover distance test in special environments. Based on the research at home and abroad, some scholars have put forward a method of measuring the crossover distance of transmission lines based on stereo vision measurement. Based on the principle of binocular ranging, the geometric measurement model of transmission line crossing is established to realize the test of transmission line crossing distance [3]. Some scholars have also proposed a lidar -based
transmission line cross distance test method, this method is mainly based on lidar cross distance automatic detection system. In the process of system design, the working principle and composition of the system are described, the test results are pretreated and optimized, and the final test results are obtained [4]. When these two methods are used to test the cross over distance of transmission lines, the objective function of transmission lines can not be constructed because of the complex environment, so the test error is large. So this paper introduces a multi-objective ant colony algorithm, which has many advantages, such as fast searching speed and high precision, to solve the objective function of transmission line crossover distance estimation, so as to obtain the optimal solution of transmission line crossover distance test.

2. TEST METHOD DESIGN OF TRANSMISSION LINE CROSSING DISTANCE

2.1. Statistics of actual information about crossover objects

First of all, the actual information of different crossover objects is counted, including eight aspects, as shown in Table 1.

| Serial number | Crossover runner                  | Statistical content                                                                 |
|---------------|-----------------------------------|-------------------------------------------------------------------------------------|
| 1             | Trees and forest area             | The spatial coordinates of tree age, tree height, tree species and distance between poles and towers with low poles were calculated. |
| 2             | Buildings (houses, etc.)          | The spatial coordinates of building materials, building quantity and distance of low hanging point pole and tower are calculated. |
| 3             | Aqueduct, ropeway and other facilities | Statistics facilities materials, access, name, quantity, low suspension point pole and tower near the space coordinates of facilities. |
| 4             | Underground pipelines (oil and gas pipelines, etc.) | Statistics transportation materials, pipeline materials, pipeline access, pipeline name, low suspension point near the space coordinates of underground pipelines. |
| 5             | Railway and highway              | Calculate the actual coordinates of the intersection, the railway and highway mileage, the actual route names of the railway or highway at the intersection. |
| 6             | Lakes and rivers                  | Calculate horizontal elevation, distances across, and names of lakes or river courses. |
| 7             | Weak wire                         | Statistical intersection point corresponding space coordinates, wire material, line name. |
| 8             | Transmission high voltage line    | The actual coordinates of the intersection point, the actual coordinates of the hanging point, the corresponding coordinates of the four poles and towers, the pole and tower model, the projection angle of the line, the wire material, the voltage class of power transmission, and the name of the line. |

In statistical table content, when the transmission line suspensions of equal height phenomenon, any one of the towers on the coordinates to calculate [5].

2.2. Construct objective function

The transmission line is regarded as a flexible cable and the catenary model in the conductor flexible cable model is used as the objective function of the transmission line [6]. Firstly, the transmission line is analyzed, and the transmission line is separated, as shown in Figure 1.
In Figure 1 (a), overhead wires are suspended between points A and B, where A is the lower end and B is the upper end, the wire gap is $h$, O is the lowest, A is $a$, and B is $b$ \(^7\).

Assuming that the load $\gamma$ acting on the overhead conductor is uniformly distributed, the corresponding horizontal component $\sigma_0$ of the actual stress at each point on the transmission line is equal on the basis of the force balance condition \(^8\). In order to facilitate the analysis of the forces on transmission lines, one of the conductors needs to be separated, as shown in Figure 1 (b). The length of separated conductor is expressed by $L$, the corresponding load of transmission line is expressed by $\gamma L$, the corresponding axial stress of point $M$ is expressed by $\sigma_x$, and the angle formed by horizontal is expressed by $\theta$. Based on the actual conditions of the transmission line, the following equations exist:

$$\tan \theta = \frac{dy}{dx} = \frac{\gamma L}{\sigma_0} \quad (1)$$

In equation (1): $x$ and $y$ represent the horizontal and vertical axes of the coordinate system with O as the origin. Therefore, the equation is also the corresponding differential equation of the catenary, which is treated differentially again as shown in the following equations:

$$d(\tan \theta) = d\left(\frac{\gamma}{\sigma_0}L\right) = \frac{\gamma}{\sigma_0}\sqrt{1 + \tan^2 \theta} \quad (2)$$

When the equation (2) is shifted and integrated, the following equations are obtained:

$$\frac{dy}{dx} = s h \left(\frac{\gamma}{\sigma_0}(x + C_1)\right) \quad (3)$$

In equation (3): $s$ for the number of shifts, $C_1$ for the integral threshold \(^9\).

The corresponding catenary point equation of transmission line is obtained according to equation (3) and boundary conditions. Boundary conditions such as equations (4). The corresponding catenary point equation of transmission line is concrete as the equation (5).

\[
\begin{align*}
    x &= 0 \\
    y &= 0
\end{align*}
\]
In equations (4) and (5), $c$ represents the boundary threshold. According to equation (5), the relationship between $a$ and $b$ can be analyzed as follows:

$$
\begin{align*}
(a + b) &= 1 \\
\gamma h \left( y(b) - y(-a) \right) &= h
\end{align*}
$$

(6)

$$
\begin{align*}
a &= \frac{1}{2} - \frac{\sigma_0}{\gamma} \frac{h}{\sigma_0} \\
b &= \frac{1}{2} + \frac{\sigma_0}{\gamma} \frac{h}{\sigma_0}
\end{align*}
$$

(7)

Based on equation (6) ~ (7), an objective function for estimating the crossover distance of transmission lines is constructed, as shown in equation (8):

$$
H = y(a) = \frac{\sigma_0}{\gamma} \left( c h \frac{\gamma}{\sigma_0} - 1 \right) - \frac{h}{2}
$$

(8)

In equation (8), $H$ represents the height from point A to the bottom of the wire [10]. The optimization criteria and constraints of this function are all the optimization of transmission line crossover distance.

2.3. Transmission line crossover distance test

Based on the statistical information of different crossover objects and the constructed objective function [11], the multi-objective ant colony algorithm is used to solve the function iteratively, and the optimal solution of the function is output to obtain the optimized results of the crossover distance test of transmission lines.

At the initial time, $n$ nodes shall be set up on the lines where the power transmission lines intersect with highways, railways, cableways, pipelines, power lines and communication cables, as well as the lines formed by the power transmission lines crossing rivers, mountains, forests and buildings. And put $m$ ants on the nodes randomly.

Each ant chooses the next mobile node according to the state transition rule. During this process, the ant chooses a higher pheromone concentration and a shorter route [12]. Each ant is equipped with a search tabu list, will not go to the node they have been to. In each cycle, local pheromone updates are performed on the ant's path. In each round, all the ants looped once, then recorded the shortest path, and enhanced the left pheromone on the shortest path according to the global pheromone updating rules. Iterations are then repeated until the transmission line crossover distance is obtained [13].

The specific test procedures are as follows:

Step 1: Ant Colony $A(t)$ Initialization: Set the relevant parameters as shown in Table 2.
### TABLE 2. PARAMETER SETTINGS AND THEIR MEANINGS

| Serial number | Parameter | Meaning |
|---------------|-----------|---------|
| 1             | m         | Number of ants |
| 2             | n         | Number of nodes |
| 3             | nc        | Cycles |
| 4             | nc_max    | Maximum number of cycles |
| 5             | Alpha     | Heuristic pheromone factor |
| 6             | Beta      | Heuristic expectation factor |
| 7             | ρ         | Volatile Pheromone Factor |
| 8             | Q         | The global pheromone update rule enhances the strength of the pheromone left on the shortest path |
| 9             | ξ         | Local pheromone volatilization factor |
| 10            | q         | Pseudorandom factor |

Step 2: Random Distribution: Randomly place \( m \) ants on \( n \) nodes \[^{14}\].

Step 3: Status update

1. Keep updating the local pheromone until all the ants have constructed a complete path.
2. Global update pheromone.

The status update rules are as follows:

For each ant \( k \), the path \( R^k \) memory vector records the specific serial numbers of all the passing nodes of the ant according to the visit order \[^{15}\]. Given that it is currently on the \( i \) node, the next node it will visit is \( j \), as shown in equation (9):

\[
j = \begin{cases} \arg \max_{j \in J_k} \left[ (\tau(i,j))^{\text{alph}} \left[ \eta(i,j) \right]^{\text{max}} \right] & \text{if } q \leq q_0 \quad (9) \\
S \text{ others} &
\end{cases}
\]

In equation (9): \( J_k(i) \) represents the set of path \( R^k \) memory vectors; \( \tau(i,j) \) represents the amount of pheromone existing on edge \((i,j)\); \( \eta(i,j) \) represents heuristic information; and \( S \) represents random variable generated by probability distribution.

The formula for updating pheromones locally is as follows:

\[
\tau(i,j) = Q(1-\xi) \cdot \tau(i,j) + \xi \cdot \tau_0 \quad (10)
\]

In equation (10): \( \tau_0 \) represents the actual initial value of the pheromone.

The equations used to update pheromones globally are as follows:

\[
\tau(i,j) = (1-\rho) \cdot \tau(i,j) + \rho \cdot \Delta \tau_k(i,j), \forall (i,j) \in R^k \quad (11)
\]

In equation (11): \( \Delta \tau_k(i,j) \) represents the global range of pheromone values \[^{18}\].

Step 3: Terminate: When the termination condition is met, the test is terminated. When the termination condition is not met, then \( nc = nc + 1 \), go to the third step to loop again. The termination condition is the maximum number of times \( nc \_ \text{max} \) in the loop to be satisfied.

Step 4: The result is output.

The process of multi-objective ant colony algorithm is shown in Figure 2.
3. **EXPERIMENTAL VERIFICATION**

3.1. **Experimental method**

In order to verify the performance of the multi-objective ant colony algorithm based transmission line crossover distance test method designed in this paper, experimental verification is carried out. The transmission lines in the experiment are two parallel single-loop transmission lines, ZB401 and ZMC1-3A1 respectively, which are shown in Figure 3.

![Image](https://example.com/image1.png)  
(a) ZB401  
(b) ZMC1-3A1

Figure 3. Tower type of two transmission lines

Among them, ZB401 is the use of steel-cored aluminum wire six split conductor, the specific model for the LGJ X6-50/400, ground for a 120-OPGW cable, the other is 100-GJ stranded steel wire. ZMC1-3A1 uses 2×425-JLHA3 type two split aluminium alloy stranded wire, one of which is 120-OPGW type optical fiber cable, the other is 100-GJ type steel stranded wire.

The mechanical characteristic parameters of the experimental transmission lines are shown in Table 3.
TABLE 3. MECHANICAL CHARACTERISTIC PARAMETERS OF EXPERIMENTAL TRANSMISSION LINES

| Project                      | Earth wire | Wire                          |
|-----------------------------|------------|-------------------------------|
|                             | 120-OPGW type | 100-GJ type | LGJ X6 - 50/400 type | 2×425-JLHA3 type | Unit |
| Outside diameter            | 16.0       | 13.0                         | 30.0                   | 27.3             | mm   |
| Cross section               | 145.67     | 101.98                       | 530.86                 | 450.44           | mm²  |
| Subconductor actual spacing | -          | -                            | 400                    | 400              | mm   |
| Mass per unit length        | 0.948      | 0.810                        | 1.677                  | 1.522            | kg/m³ |
| Tensile Strength            | 174.3      | 116.5                        | 122.9                  | 118.3            | kN   |
| Coefficient of elasticity   | 1.54X10⁸   | 1.82X10⁸                     | 6.6X10⁴               | 7.0X10⁴          | N/mm² |
| Expansivity                 | 1.3X10⁻⁵   | 1.2X10⁻⁵                     | 2.1X10⁻⁵              | 2.0X10⁻⁵         | °C⁻¹ |
| Actual strength safety factor | 3.6        | 3.1                          | 2.4                    | 2.4              | -    |

Since the baseline distance is the range within 15m-35m where the test errors are most likely to occur, experimental tests are performed within a range.

The parameters of multi-objective ant colony algorithm used in this paper are \( m = 32 \), \( n = 14 \), \( Q = 100 \), and the number of iterations is 500.

In order to avoid the experimental results being too single and lack of comparison, the above two methods are used as the comparison method. The two methods are based on stereo vision measurement and based on lidar, which are used in the test of transmission line crossover distance.

(1) Distance estimation accuracy

In order to test the performance of the three methods, the accuracy of the distance estimation was tested. The formula for calculating the accuracy of the distance estimation is as follows:

\[
W = \frac{H}{H_{\text{actual}}} \times 100\% \quad (12)
\]

In equation (12): \( H_{\text{actual}} \) refers to the measured value of the crossing distance of transmission lines. The comparison of the distance estimation accuracy of the three methods is shown in Figure 4.

![Estimated accuracy](image)
Analysis of Fig. 4 shows that the accuracy of range estimation based on stereo vision method is between 45% and 95%, and that based on lidar method is between 43% and 63%. Compared with the experimental results, the estimation accuracy of the multi-objective ant colony algorithm for transmission line crossover distance test is maintained at more than 89%. It is shown that the proposed method can obtain accurate estimation results of cross over distance of transmission lines, which lays a solid foundation for future research.

(2) Measurement error

In the 15m-35m baseline distance range, the measurement errors of the three transmission line cross-distance test methods are shown in Table 4.

| Baseline distance (m) | Method based on multi-objective ant colony algorithm | Method based on stereo vision measurement | Lidar-based method |
|-----------------------|-----------------------------------------------------|----------------------------------------|-------------------|
| 15                    | 0.21                                                | 0.85                                   | 0.46              |
| 16                    | 0.15                                                | 0.56                                   | 0.42              |
| 17                    | 0.18                                                | 0.55                                   | 0.47              |
| 18                    | 0.17                                                | 0.57                                   | 0.51              |
| 19                    | 0.18                                                | 0.58                                   | 0.39              |
| 20                    | 0.37                                                | 0.51                                   | 0.48              |
| 21                    | 0.14                                                | 0.50                                   | 0.54              |
| 22                    | 0.17                                                | 0.60                                   | 0.54              |
| 23                    | 0.09                                                | 0.64                                   | 0.56              |
| 24                    | 0.12                                                | 0.64                                   | 0.48              |
| 25                    | 0.11                                                | 0.56                                   | 0.48              |
| 26                    | 0.10                                                | 0.57                                   | 0.50              |
| 27                    | 0.14                                                | 0.58                                   | 0.60              |
| 28                    | 0.17                                                | 0.58                                   | 0.48              |
| 29                    | 0.09                                                | 0.51                                   | 0.54              |
| 30                    | 0.05                                                | 0.50                                   | 0.48              |
| 31                    | 0.18                                                | 0.54                                   | 0.52              |
| 32                    | 0.37                                                | 0.55                                   | 0.44              |
| 33                    | 0.16                                                | 0.55                                   | 0.50              |
| 34                    | 0.11                                                | 0.57                                   | 0.54              |
| 35                    | 0.17                                                | 0.55                                   | 0.46              |

According to the test error comparison data in Table 4, within the baseline distance of 15M-35M, the maximum error based on stereo vision measurement method is 0.85m, and the minimum error is 0.5m. The maximum error of lidar method is 0.6m and the minimum error is 0.42m. The maximum test error of the method based on multi-objective ant colony algorithm is 0.37m, and the minimum is 0.05m. The test error of this method is lower than that of experimental comparison method, which verifies the superiority of this method.

(3) Testing time

On the basis of the above experiments, the test time of three methods is compared, and the results are shown in Figure 5.
Analysis of Figure 5 shows that the test time based on stereo vision measurement varies between 0 and 4.2s. The test time based on the lidar method varies from 0-3.3s. However, the test time of the method based on multi-objective ant colony algorithm is always less than 0.5 s, which shows that the method is short and can complete the test in a short time.

4. CONCLUSION

The transmission line is the channel of electric energy transmission, is an essential part of the grid, its reliability is directly related to the smooth development of national economy. However, the safe operation of transmission line is affected by crossing for a long time, and the distance between transmission line and crossover will change when strong wind, subsidence, tree growth, temperature change, wire aging and other factors. When the spacing is too small, a discharge will occur between the conductor and the crossover, which will lead to the accident. With the development of the power industry, it is more and more important for line operators to choose a reasonable method to estimate the crossing distance of overhead transmission lines. In order to improve the security of transmission lines, a cross-over distance testing method based on multi-objective ant colony algorithm is designed. The multi-objective ant colony algorithm is used to solve the model for several times, and the results of transmission line crossover distance test are given. Experimental results show that the proposed method has high precision, small error and short test time, and can effectively avoid the occurrence of line discharge accidents.

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