Research on Three-Dimensional Routing Inversion and Modeling Method of Top Pipe Based on Gyroscope Three-Dimensional Positioning Technology

Long Xu*

[1]Guangzhou Power Supply Bureau of Guangdong Power Grid Co.,Ltd., Guangzhou, Guangdong, 510620, China

*Corresponding author's e-mail:ly0734xulong@163.com

Abstract. In view of the shortcomings of traditional pipeline detection methods such as susceptibility to external interference, low detection precision and poor accuracy, this paper adopts gyroscope 3D positioning technology to obtain high-precision detection data of the roof pipe (electric power pipeline), and through data fusion and inversion, it deduces the parameters such as the location, direction, depth and shape of the underground roof pipe; at the same time, using the 3D rapid modeling method of the roof pipe with the synergy of BIM and 3D GIS, the high precision 3D model of the roof pipe can be established quickly and efficiently. At the same time, using BIM and 3D GIS synergistic three-dimensional rapid modeling method of the roof pipe to quickly and efficiently establish a high-precision three-dimensional model of the roof pipe, and then integrated with the urban planning system to realize the three-dimensional display of the spatial distribution status of the underground pipe network under the background of the urban geographical information. Finally, through VR and AR technologies, users can view the layout of the underground pipe network in 3D, which is more intuitive than the traditional 2D plan. Users can freely rotate, zoom and move the viewpoint to better understand the structure and layout of the pipe network. The experimental results show that the research pipe laying method is clear and intuitive, realizes the safety delivery to external construction units, provides a reliable model support for the operation and maintenance management of underground electric power pipelines, and has a wide range of application prospects in the planning and management stage of underground pipelines for electric power, gas, drainage and other underground pipelines.

Keywords: pipe jacking; gyroscope; data acquisition; Kalman filter fusion; three-dimensional modeling

1 Introduction

With the rapid development of China's economy and society and the increasing demand for electricity, in order to save urban surface space resources, power line planning and

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construction gradually shifted from the ground to the underground space, the underground power channel network system is increasingly developed, the line layout is intricate. Among them, pipe jacking, as a technical method that can complete underground pipeline laying without excavating the ground surface, has been widely used in modern electric power engineering construction by virtue of its advantages of low comprehensive cost, short construction period, small environmental impact, and no impact on traffic [1]. The current use of non-excavation laying of pipe jacking is generally buried deeper (3 ~ 30 m), the traditional completion of the measurement method of metal pipeline detector or guided locator, the signal transmitting source into the pipeline drag, by the ground detector tracking reception of the transmitter signal to determine the depth and direction of the pipeline. Such methods in addition to their own detection characteristics, easily subject to geomagnetic field interference, burial depth and other factors, detection accuracy is low, difficult to accurately locate the position of the pipeline and depth of burial, can not meet the needs of pipeline acceptance of the completion of the system has been affected by the management of the management unit of the underground power pipeline network system management and maintenance [2]. Therefore, how to accurately detect the location and depth of underground electric power pipelines, and realize the three-dimensional visualization management of electric power pipelines has become an urgent task for the operation and maintenance management of underground electric power pipeline network.

Wan Jinhao [3] et al. proposed a data downlink routing algorithm for three-dimensional sparse wireless actuator networks, which calculates the position deviation angle, establishes a set of candidate nodes for data downlink routing, and carries out a preliminary screening of the surrounding nodes. Meanwhile, when the number of candidate nodes for data downlink routing is too small, the maximum position deviation angle correction method is proposed to improve the selection range of candidate nodes, and finally select the appropriate candidate nodes to complete the data transmission. However, the success rate of this method is still to be improved. Peng Zhang[4] and others proposed a study on the stability of circular working wells for pipe jacking construction based on a three-dimensional finite element numerical model. By establishing a three-dimensional finite element numerical model of pipe jacking construction and working wells, the study simulates the pipe jacking construction process dynamically and verifies it with the measured data. Yang Lu [5] and others proposed the three-dimensional deformation characteristics of the composite structure of the ultra-deep pipe jacking working well to improve the supporting efficiency and overall stability of the working well structure by setting up the necessary inner liner walls and setting the interval of each internal support to decrease with the decrease of its distance from the center of action of jacking reaction force. However, the accuracy of the numerical simulation results and the actual monitoring values of this method still needs to be improved.

Inertial gyro locator three-dimensional positioning technology can accurately record the spatial trajectory of underground electric power pipeline, accurately determine the three-dimensional spatial coordinate data of the pipeline, effectively solving the accuracy problem that cannot be solved by other detection means. The technology combines gyroscope orientation, inertial navigation, computer three-dimensional calculation and other technologies, drag the inertial gyro locator through the pipeline to be tested, through automatic tracking to record the trajectory of its movement within the pipeline, to generate the three-dimensional coordinates of the pipeline center axis and the location map [6]. This method is subject to less external interference, as long as the inertial gyro-positioner can travel in the power pipeline to be measured, it can realize high-accuracy pipeline measurement. Meanwhile, the detection results can be fused with GIS data, and based on the precise attitude and motion information provided by the gyroscope sensors, combined with data fusion and mathematical modeling, more accurate 3D modeling and visualization of underground power pipelines can be achieved, providing more reliable data support for power pipeline management and planning [7].

2 Gyroscope Three-Dimensional Positioning Technology Analysis

2.1 Working Principle of Inertial Gyro-Positioner

The inertial localizer consists of a gyroscope assembly and an accelerometer assembly, which measure the components of the three rotational angular velocities and the three linear accelerations along the coordinate system of the localizer, respectively, and undergoes a coordinate transformation to convert the acceleration information into the navigation coordinate system acceleration, and to compute the position, velocity, heading, and attitude of the localizer [8].

2.2 Three-Dimensional Modeling Realization of the Roof Pipe

Revit in the tunnel engineering modeling process there are many repetitive work, low efficiency and other issues, according to the modeling needs of the secondary development of Revit API, Revit API is Revit provided to the user's application program interface, the user can be with NET-compatible programming languages (VB, C + + +, C #) combined with the Revit API function provided by the Revit API method of secondary development [9]. Revit API contains a large number of class libraries, which can be used to expand and optimize the software functions on the basis of API, read the roof pipe modeling data by modifying the registry and adding the corresponding key value methods, and realize the automatic loading of the modeling program, so as to improve the accuracy and efficiency of the modeling [10].

The modeling process includes data reading, pipe style setting, structure style setting, creation of parts list and structure dynamic attributes, etc. The modeling flow is shown in Figure 1:

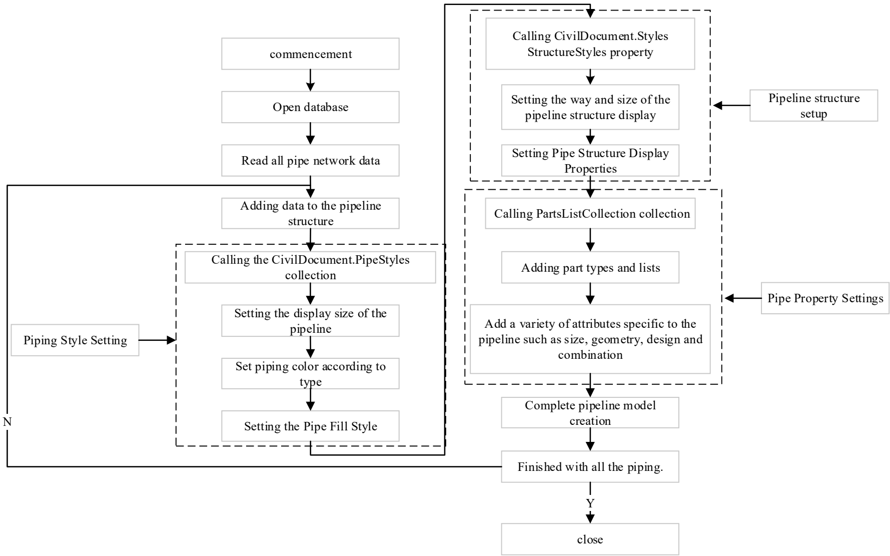

Fig. 1. Flow chart of roof pipe modeling

3 Data Fusion and Inversion

3.1 Data Pre-Processing

After the detection work is completed, the specialized data processing system software is used to calculate and process the measurement information to get the pipeline positioning information data. According to the processing results to assess the data quality and accuracy of the validity of the data, if not to meet the requirements, it is necessary to carry out a retest, until the most accurate results are obtained. After obtaining the more accurate results, the complete data obtained from this detection is saved for further data processing and three-dimensional refinement modeling work [11].

3.2 Kalman Filter Fusion Attitude Data

Due to the existence of various random noise and errors in the gyroscope, the direct angular velocity output will have a large jitter, so it is necessary to design a low-pass filter to smooth the original signal and filter out the high-frequency noise as much as possible [12].

Kalman filtering is utilized to fuse the attitude data, and the Kalman filtering algorithm is used to filter the system on a time scale, and to describe the system using a constantly updated state, so that the noise generated by the system does not become a factor affecting the accuracy, but can be characterized statistically and utilized in the process of state estimation, and the "prediction-correction" process is continuously performed in the calculation. "Instead of storing a constant stream of data, a new filter can be calculated as soon as a new sample value is observed. Multiple attitude angle information measured is utilized to estimate the error of the measurement system and to make corrections. Gyroscope sensors can integrate the angular rate signals transmitted by themselves to solve the attitude; while accelerometer sensors can solve the attitude without offset error under multiple noises; Kalman filtering method can combine the attitude situations in these two different cases, calculate the Kalman gain, and fuse the multiple attitudes to solve the attitude closest to the actual situation [13].

3.3 Optimal Data Processing Planning based on Ant Colony Algorithm

The transfer state of the ant colony between two nodes is determined by the amount of pheromone transferred by the ants between the two nodes. When in time t, the transfer probability of ants from current node i to node j is P_{ij}^{M} can be expressed as:

$$\mathrm{P}_{\mathrm{ij}}^{M}=\begin{cases}\dfrac{[T_{\mathrm{ij}}(\mathrm{t})]^{\gamma}[\rho_{\mathrm{ij}}(\mathrm{t})]^{\theta}}{\sum_{D\subset A}[T_{\mathrm{id}}(\mathrm{t})]^{\gamma}[\rho_{\mathrm{id}}(\mathrm{t})]^{\theta}}D\in A\\ 0 \qquad\qquad \text{otherwise}\end{cases} \tag{1}$$

$$\rho_{\mathrm{ij}}=\frac{1}{\mathrm{q}_{\mathrm{ij}}} \tag{2}$$

Where: T_{ij} is the amount of pheromone on the point i to point path at time t, γ is the heuristic factor, θ is the size of the desired heuristic factor, ρ_{id} is the amount of heuristic information on the point i to point path at time t, ρ_{ij} is the reciprocal of the distance between the two nodes of ij, and A is the set of paths that the ants can reach in the transfer process.

When an iteration ends, there are residual pheromones on each path, which need to be updated in order to make the solution have more diversity and higher quality:

$$T_{\mathrm{ij}}(\mathrm{t}+N)=(1-\alpha)*T_{\mathrm{ij}}(\mathrm{t})+\Delta T_{\mathrm{ij}},\ \ \alpha\in(0,1) \tag{3}$$

$$\Delta T_{\mathrm{ij}}(\mathrm{t})=\sum_{M=1}^{v}\Delta \mathrm{T}_{\mathrm{ij}}^{M}(\mathrm{t}) \tag{4}$$

where $T_{\mathrm{ij}}(\mathrm{t}+N)$ is the pheromone increment of the ant after completing one iteration; $\Delta T_{\mathrm{ij}}(\mathrm{t})$ is the pheromone increment of ant k after completing one iteration, and α is the pheromone enhancement coefficient with a magnitude between 0 and 1.

3.4 Data Output

The following is the pipe jacking detection data and pipe jacking trajectory solving results for a section of power line in Guangzhou. Pipeline No. DL1-1, the measurement base adopts Guangzhou 2000 plane coordinate system and Guangzhou urban construction elevation system, the diameter of the power pipe is 225mm, and the material of the pipe is MPP pipe. The three-dimensional coordinate results of the three-dimensional trajectory inertial localization measurement of the pipe section of the DL1-1 underground pipeline are shown in Table 1:

Table 1. DL1-1 underground pipe three-dimensional trajectory inertial positioning measurement pipe section trajectory three-dimensional coordinates results table

mileage	3D coordinate system			Depth from road surface to top of pipe	note
	north coordinate (m)	east coordinateY(m)	Elevation in the pipeH(m)	depth of burial(m)	
0	255767.801	49305.895	22.135	1.34	
1	255768.289	49306.766	22.075	1.40	
2	255768.774	49307.638	22.008	1.47	
3	255769.247	49308.514	21.919	1.56	
4	255769.704	49309.394	21.79	1.69	
5	255770.154	49310.271	21.62	1.86	
6	255770.606	49311.140	21.422	2.06	
7	255772.475	49314.554	20.502	2.98	

A simulation of the test pipe jacking probe trajectory is shown in Figure 2:

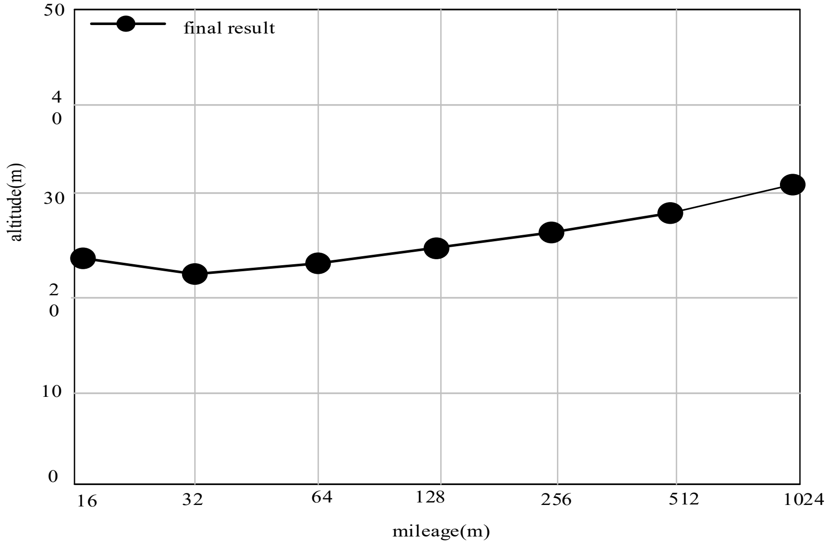

Fig. 2. Simulation of test pipe jacking probing trajectory

4 Experimental Analysis

In order to verify the accuracy of the research on 3D routing inversion and modeling method of top pipe based on gyroscope 3D positioning technology proposed in this study, the results of testing and verifying the autonomous software from both static results and creep results are shown in Fig.3:

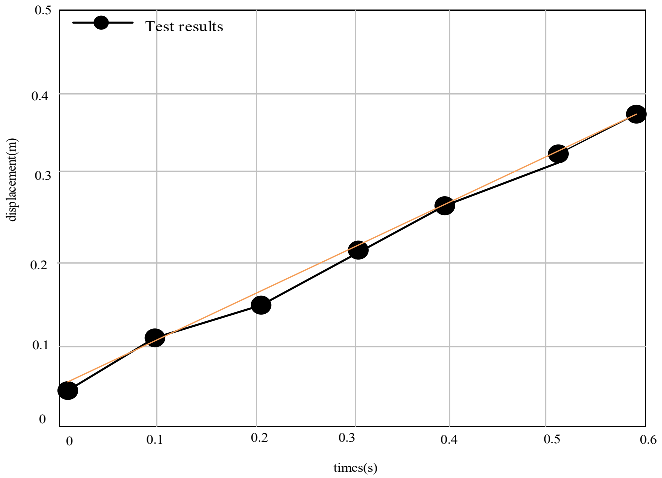

Fig. 3. Testing and validation results

As shown in Fig. 4, the test results of the research on 3D routing inversion and modeling method of top pipe based on gyroscope 3D positioning technology proposed in this paper coincide with the actual results from static force and creep results with consistency, thus verifying the accuracy of the results of the research on 3D routing inversion and modeling method of top pipe based on gyroscope 3D positioning technology. In addition, the static results and creep results of the method proposed in this paper are compared with the methods proposed in literature [3], literature [4] and literature [5] as shown in Fig. 4:

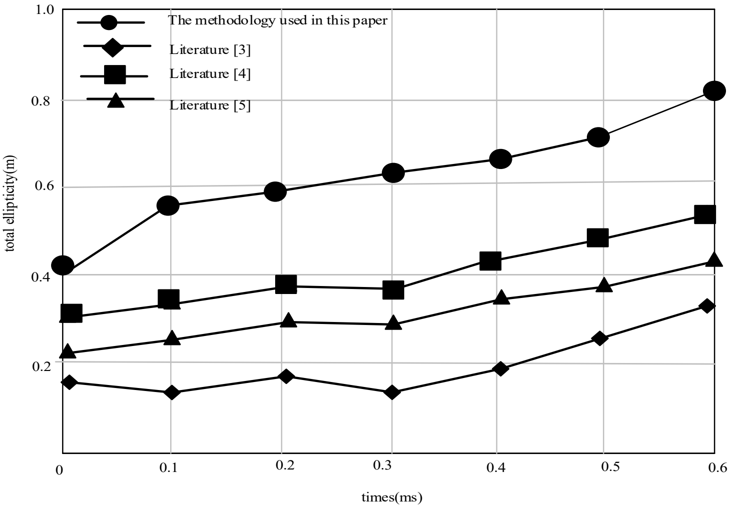

Fig. 4. Static results and creep results of the four methods

As shown in Fig. 5, the methods proposed in literature [3], literature [4] and literature [5] will lead to a reduction in the positioning accuracy of the algorithm due to the fast sampling frequency of the stationary state error, and the features are not rich, so the practical applicability of the above algorithms is low. The study of 3D routing inversion and modeling method of pipe jacking based on gyroscope 3D positioning technology proposed in this paper can provide real-time 3D position information of the pipe, which facilitates dynamic monitoring of the pipe jacking process and timely adjustment of the construction strategy. And it has significant advantages in accuracy, stability, applicability and efficiency.

Furthermore, the results of comparing the matching correctness of the proposed method in this paper with the methods studied in literature [3], literature [4] and literature [5] are shown in Fig. 5:

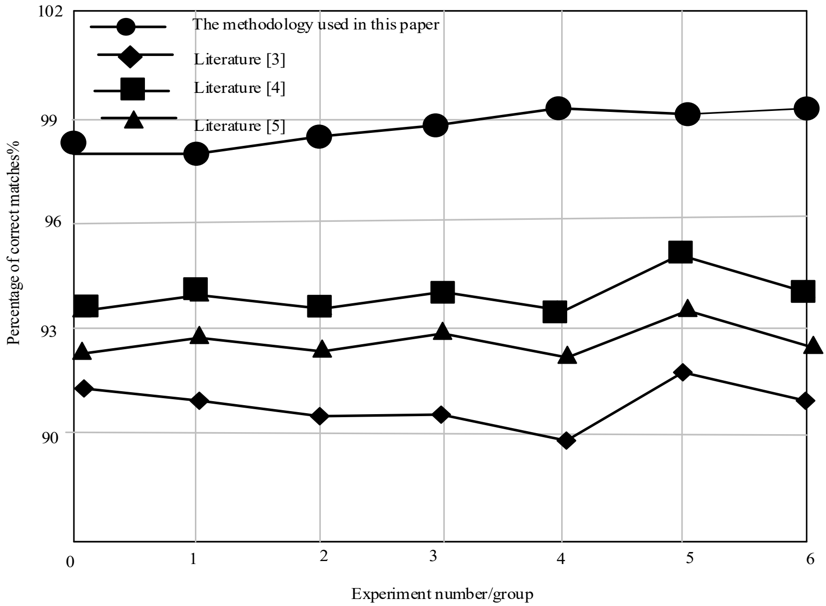

Fig. 5. Comparison results of correct matching rate of four methods

As shown in Fig. 5, the correct matching rate of the top pipe 3D routing inversion and modeling method based on gyroscope 3D positioning technology proposed in this paper is much better than that of the methods researched in the literature [3], the literature [4] and the literature [5], reaching more than 96%, in which the method researched in the literature [3] has the lowest correct matching rate. Moreover, the gyroscope-based 3D positioning technology proposed in this paper has shorter matching time, more correct matching points, and higher correct rate for the top pipe 3D routing inversion and modeling method.

5 Conclusion

According to the construction needs of the national smart grid, three-dimensional modeling technology is more and more widely used in electric power pipeline network due to the rapid development of computer technology and three-dimensional modeling technology. This paper provides a 3D routing inversion and modeling method of roof pipe based on gyroscope 3D positioning technology. Based on the high-precision detection data provided by gyroscope 3D positioning technology, the parameters such as the location, direction, depth and shape of the underground roof pipe are deduced through data fusion and inversion, and the 3D rapid modeling method of roof pipe using the synergy of BIM and 3D GIS is used to quickly and efficiently establish a high-precision 3D model of the roof pipe to achieve the The spatial distribution status of underground pipe network is displayed in 3D reality under the background of urban geographic information. The technology will show the underground pipe laying status from the previous two-dimensional plane to three-dimensional space, the pipeline laying position and direction are clear, and at the same time, it can be easily realized for the external construction unit safety briefing and strict control of production quality. The application of this technology for the underground power pipeline operation and maintenance management provides a reliable model support, in the electric power, gas, drainage and other underground pipeline planning and management stage has a wide range of application prospects.

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