Journal of Network Intelligence
Taiwan Ubiquitous Information

Volume **6**, Number **3**, August **2021**

Prevention of External Force Damage to Overhead Power Lines Based on Network and Intelligent Positioning

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Received April 2021; Revised June 2021

Abstract. *In the research on the prevention of external damage to power transmission lines, it is a difficult problem to prevent large machinery vehicles from damaging the overhead transmission lines. After the emergence of video surveillance technology, the accident rate has dropped significantly. But still unable to completely eliminate such accidents. The anti-external damage solution based on network and intelligent positioning is very effective for early warning of accidents. This gives us the opportunity to completely eliminate such accidents. In this paper we utilize the satellite positioning data of the power towers to establish a warning zone along the power line. When the system detects that some large machinery vehicles enter the warning zone, early warning messages will be sent to these vehicles. Afterward, the connection between vehicle drivers and management center can be established such that further instructions can be ordered to avoid accidents. According to our simulations, it presents our proposed mechanism can effectively prevent the damage occurrences which may be caused by large machinery vehicles.*
Keywords: Anti-external damage, Network and intelligent positioning, Overhead transmission lines.

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1. **Introduction.** With the continuous increase of large-scale infrastructure projects in southern China, the damage to overhead transmission lines caused by large-scale machinery is also increasing. As the main carrier for long-distance transmission of electric energy, the safety and reliability of overhead transmission lines are extremely important to the power grid. When large mechanical vehicles (such as cranes, pump trucks, and excavators) work near overhead transmission lines, if the driver makes a mistake (such as the robotic arm too close to the power line), it may cause the line to trip. And caused huge economic losses and casualties. According to statistics, power line interruption accidents caused by large mechanical vehicles account for about 70 % of the total number of external damage accidents in China Southern Power Grid. Such accidents have become the most important factor affecting the safety and reliability of overhead transmission lines. If an early warning is generated before a large mechanical vehicle causes an accident and the driver is reminded to drive carefully, the accident can be effectively avoided. Therefore, how to generate early warning to protect transmission lines from damage by large mechanical vehicles is a research of practical significance. In order to prevent external damage to the overhead transmission lines of China Southern Power Grid, we have proposed an early warning method for external damage based on the network and intelligent positioning. In the case of reliable equipment, the accuracy and effectiveness of this method can reach 100%. It achieves the purpose of early warning, and has the characteristics of high reliability, intelligence, strong real-time, and simple operation. The Internet of Things and positioning technology are used in the early warning process. We provide new directions and ideas for protecting overhead transmission lines from damage to large mechanical vehicles.

In power systems, overhead transmission lines are generally bare conductors. An electrical discharge may occur when the robotic arm approaches the overhead transmission line. Even if the arm does not touch the line. The discharge distance of overhead transmission lines will be affected by various factors, such as temperature, air pressure, and humidity. The degree of sagging of power lines varies between the different tower segments. This makes it difficult to accurately define the safety distance of overhead transmission lines. Therefore, drivers of large mechanical vehicles cannot make correct judgment whether they are in safe working areas or not. If not, accidents will be inevitable. In recent years, the number of such accidents has remained high. This means that either the drivers lack safety awareness or the management mechanism cannot effectively control the occurrence of accidents. Although we can detect risks by monitoring video, we cannot immediately alert drivers by using effective communication to avoid accidents.

There are mainly four cases of external force damage: (i) external force damage caused by large machinery vehicles. (ii) external force damage caused by illegal buildings. (iii) sudden and seasonal external force damage. (iv) external force damage caused by excessively high trees [1]. At present, external damage accidents caused by natural disasters or other non-human factors are well controlled, such that the number of related accidents is decreasing year by year. However, the number of external damage accidents caused by human factors is increasing year by year. Although the power grid has organized special line guards, most of them are only temporary organizations and cannot perform well. In recent years, in order to make the project on schedule, working on the night for many construction units has become more frequent. However, the current power management department cannot provide 24-hour service for overhead transmission lines. Therefore, we cannot detect and prevent accidents in time [2].

In order to prevent damages caused by external forces, traditional power grids regularly conduct manpower-based inspections on overhead transmission lines. This method has problems such as low efficiency, long cycle, time-consuming and labor-consuming. Some provinces in China have used drone-based inspections to make up for the shortcomings of traditional inspections. This method can effectively shortens the inspection time and improves working efficiency, but it still cannot play the role of real-time early warning and on-site prevention. The video surveillance system provides a new solution to prevent external damage to overhead transmission lines. Through image recognition technology, computers can help us find dangers in overhead transmission lines. Which effectively reduces the cost of manpower. However, this method also has problems such as insufficient accuracy and stability.So far, the early warning technologies used to prevent external damage to overhead transmission lines have mainly adopted the detection technologies such as video surveillance, laser ranging and field strength sensing [3]. The details are as follows:

(a) Use the intelligent video surveillance with sound and light alarm equipment to provide early warning of external intrusions. It can effectively detect damage to overhead transmission lines by external forces, However, there are some disadvantages such as limited coverage, blind spots, weather sensitivity, high false alarm rate, more power consumption, poor communication and poor warning capabilities.

(b) Use the laser ranging technology to provide early warning of external damage. The characteristics of laser ranging technology are large ranging range, fast speed and high precision. However, the total power consumption of the device is high, the cost is expensive, and it is easily affected by environmental interference. Therefore, it is difficult to apply to a wide range of applications.

(c) Use the field strength detection technology for external force damage early warning (mainly used for cranes and other large machinery). It is simple in principle and easy to implement with low cost. However, the detection objects such as cranes are most of metal materials, which are electric field sensitive materials. It is easy to cause electric field interference and distortion. Therefore, the field strength detection technology is always with poor detection accuracy and high false alarm rate. The application of this technology is limited and further improvements are needed [4-8].

(d) Use the vehicle positioning system to provide early warning of external damage. It is a simple and effective system with a low false alarm rate and high reliability to prevent external damages. Currently, the division of early warning areas is very rough, and it is necessary to install a positioning device on each engineering vehicle. But only using these positioning devices still cannot establish communication between the management department and the drivers. In addition, due to the use of civilian positioning software and technology, it is easy to cause the leakage of the position coordinate data of the overhead transmission line. This will seriously affect the security of the power grid [9].

Many countries have promulgated extremely strict power line protection laws to regulate the work of large mechanical vehicles to protect overhead transmission lines from external force intrusion. Therefore, there are fewer external damage accidents caused by large machinery such as cranes hitting the wires. In addition, foreign power companies began to study on-line monitoring technology for transmission lines as early as the 1970s, and this technology is already very mature. Online monitoring automation technology has become popular. Infrastructure construction abroad is relatively slow. According to the existing technology and laws, the risk of damage to the power cord can be effectively avoided. But in China, preventing external damage to overhead transmission lines has become more and more complicated. External damage is much more serious than abroad. This also prevents Chinese power companies from learning from foreign experience to solve practical problems.

In this paper, we propose a new mechanism based on the Internet of Things and positioning technology to prevent external damage to overhead transmission lines. The rest of the paper is organized as follows. In section 2, we introduced relatively highly relevant technologies and application examples.In section 3, we put forward a new method based on network and intelligent positioning technology to prevent external damage. It will also introduce in detail the related technologies used in the new method and the workflow of the new method. Section 4 introduce the mathematical principles of the new method and the main problems faced by the new method. Section 5 mainly introduces the source of program design and experimental data. Presents the results of simulation experiments. We proved the feasibility and reliability of this method. Finally, in section 6, we summarize our works and give a short conclusion.

2. **Related Technologies and Applications.**

Currently, there are many technologies that can be used to prevent external force damage, and there are many similar application scenarios, which will be briefly introduced below.

2.1. **Prevention of external damage based on image recognition technology.**

As image recognition technology matures, it has been widely used in engineering. In [10-11], SSP and LBP are proposed for applying to the facial recognition. In [12], a novel feature extraction mechanism called AQKDA (Adaptive Quasiconformal Kernel Discriminant Analysis) is proposed, which can effectively extract image features, and can effectively improve accuracy when identifying large objects such as large construction vehicles. In [13], PMVO is used to achieve higher quality image segmentation, which will effectively improve the search speed in image recognition. In [14-15], convolutional neural networks have been used to reach the level of speech recognition through lip images.

The structure of the online monitoring system used to prevent external forces from damaging the overhead transmission lines is shown in figure 1. In response to the threat of external damage to overhead power lines, power companies can use intelligent image recognition technology to detect abnormal objects entering the vicinity. On this basis, they also developed an intelligent response mechanism for early warning. This method replaces the traditional manual inspection and realizes online monitoring. The system includes image acquisition front-end equipment, data transmission processing platform, online detection program and network information security protection program. In [16], the front-end equipment of image acquisition and the data transmission software and

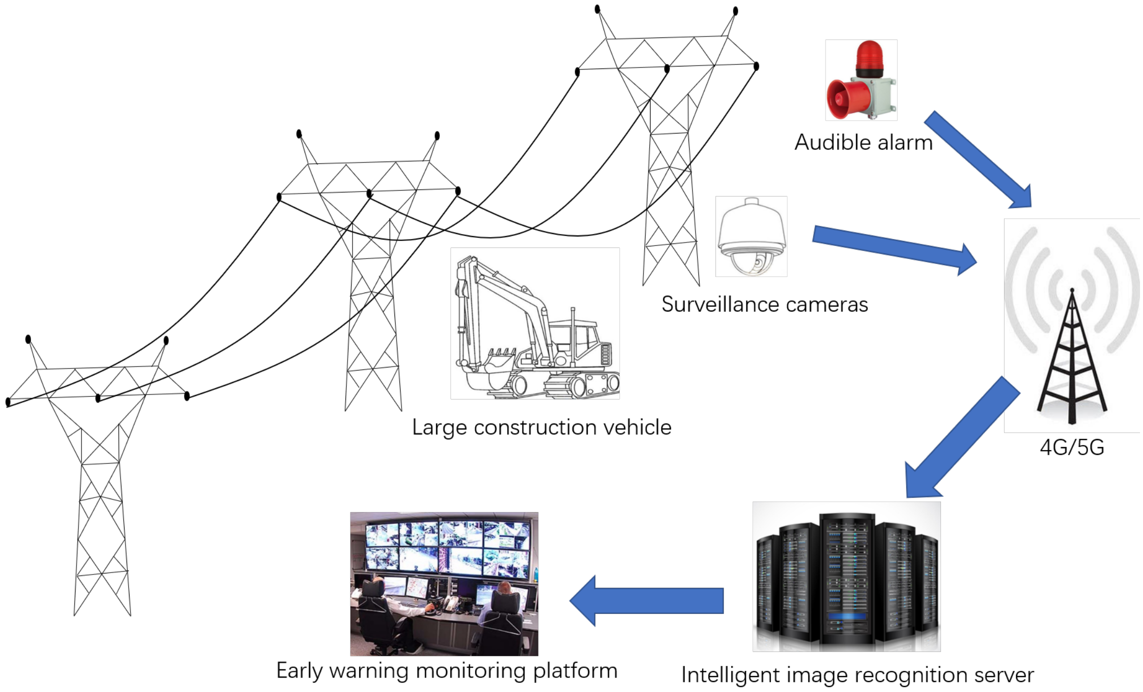

FIGURE 1. Schematic diagram of the structure of the anti-damage system based on image recognition

hardware platform are designed in detail. Based on the above design, the purpose of transmitting the front-end field image information to the monitoring center server is realized. Figure 2 is a diagram of the system framework. In [17], energy-saving routing methods for large-scale networks are mentioned. The video monitor can also be regarded as a node to some extent. If this method is used to improve the routing protocol of the video monitor cluster, the stability of monitoring will be greatly improved.

After the images are collected and transmitted to the server, the Faster R-CNN image recognition intelligent algorithm will be used to identify the type of intrusion. In [16-18], Faster R-CNN is used for regional image recognition based on deep learning. The architecture includes three parts: the feature extraction part, the region generation part to be selected, and the target classification part. The function of the feature extraction part and the candidate region generation part is to form the candidate region generation network of Faster R-CNN. The feature extraction part and the target classification part together form the Faster R-CNN detector. The two main modules, the region-to-be-selected generation network and the Fast R-CNN detector constitute the Faster R-CNN architecture. These two modules jointly use feature extraction convolutional layers [19-22].

They also verified the effectiveness of the early warning system based on image recognition by inspecting various external damages of a certain city power company. The external force damage scenariose include the damages caused by large super high machinery, tower machinery, bush growth, kite suspension, etc. 100 scenarios have been inspected. The false alarm rate and accuracy rate of the 220 kV power line external loss prevention early warning system are calculated. The specific test results are listed in table 1.

For ultra-high machinery, tower foundation construction, kite suspension and other external force damage, the system has operated well with a low false alarm rate and a high alarm accuracy rate. However, the alarm accuracy rate in the scenario of ultra-high machinery is only 97.98 %, and the false alarm rate is 1 %. This is far from enough to protect

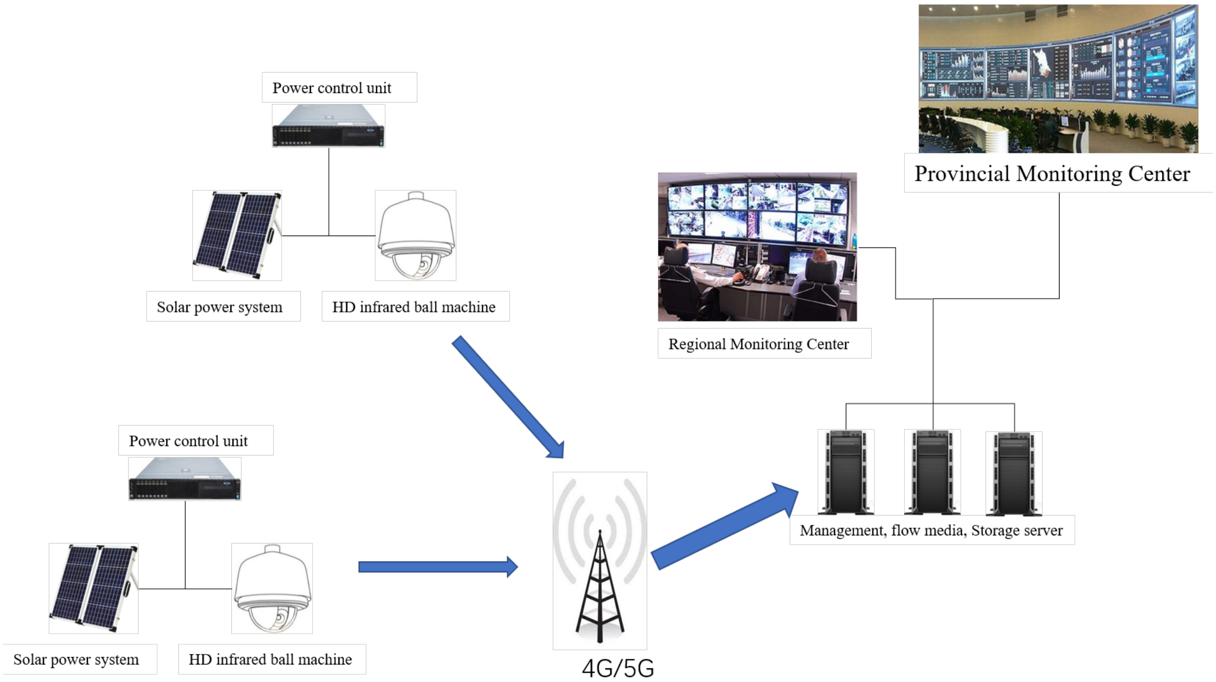

FIGURE 2. System architecture for preventing external damage based on image recognition

TABLE 1. Test data of 220 kV transmission line online inspection system

Test Environment	Heavy machinery	Tower Crane	Shrub growth	Kite hanging
warnings	99	98	96	99
Missing	1	2	4	1
Errors	2	1	11	3
Missing ratio/%	1	2	4	1
Accuracy/%	97.98	98.95	88.54	96.97

the safety of the power cord because the small image acquisition range and the large blind area of video surveillance. In [23-25], wireless sensor networks and GADO methods are mentioned. In [26-28], the security protocol for wireless sensor network data transmission is mentioned. These methods can effectively optimize sensor scheduling strategies, reduce the number of central nodes and data transmission delay, and improve security at the same time. It can also be used to optimize the distribution of surveillance cameras. This will enable each surveillance camera to have the best surveillance range and eliminate a large number of surveillance blind spots. But, without considering the warning range and blind zone, the method will still miss and false alarms. In practical applications, this may cause a large number of accidents. Therefore, it is necessary to completely eliminate the false alarm rate and further reduce the false alarm rate.

2.2. **Public bicycle management system based on high-precision positioning.** At present, shared bicycles have been widely used in China, but at the same time, the random parking problem of shared bicycles has also become a new challenge for urban management. In [29], the author proposed a public bicycle management method based on high-precision positioning technology. The system composition is shown in figure 3.

In [29], it also uses the functions of the Beidou satellite navigation system, and is

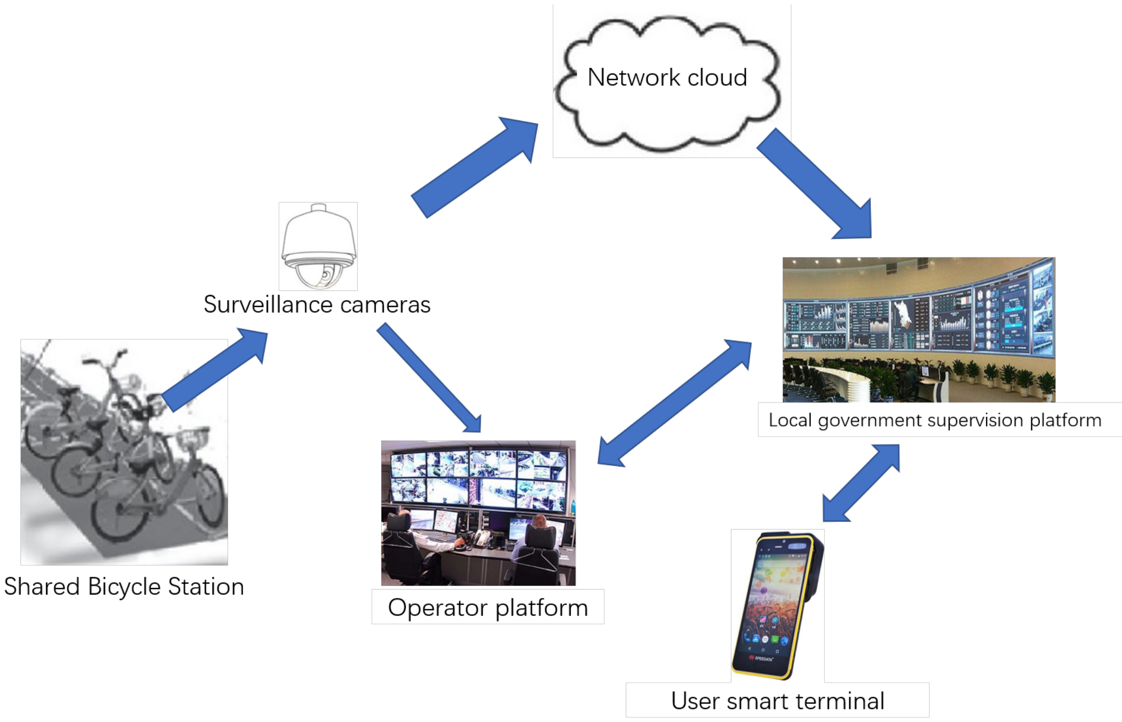

FIGURE 3. Schematic diagram of high-precision positioning and pile-free public bicycle system

used in conjunction with the smart lock installed on the bicycle and the positioning stake installed in the parking area to quickly locate the bicycle. In addition, Internet of Things technology and platforms are also used in to effectively establish the connection among bicycles, government regulators and operators. And the problem of random parking of bicycles can be solved. The use of electronic fence technology is mentioned. The schematic diagram of using this technology to divide the parking area is shown in figure 4.

The positioning technology used in [25] is similar to the intelligent positioning technology studied in this paper. It can be used to prevent external forces from damaging overhead power lines. Regional division and system composition also are similar. However, the electronic fence technology is not suitable for long and narrow overhead power line corridors. If you want to form a rectangular area similar to Figure 4 under the overhead power line, you must place many positioning stakes to meet the requirements. In addition, there are a large number of overlapping areas of electronic fences in the positioning stakes, which is a waste of resources to a certain extent.

2.3. **Anti-explosion system based on positioning technology.** The power company proposed the idea of using vehicle positioning technology to prevent overhead power lines from being damaged by external forces. Power companies have now strengthened the application of surveillance video and image recognition. From the perspective of effectiveness, the number of external injury incidents has decreased. But in recent years, the number of external injury accidents does not decrease continuously. This shows that video surveillance cannot further reduce external damage. At present, external damage accidents caused by large-scale event machinery and vehicles have accounted for more than

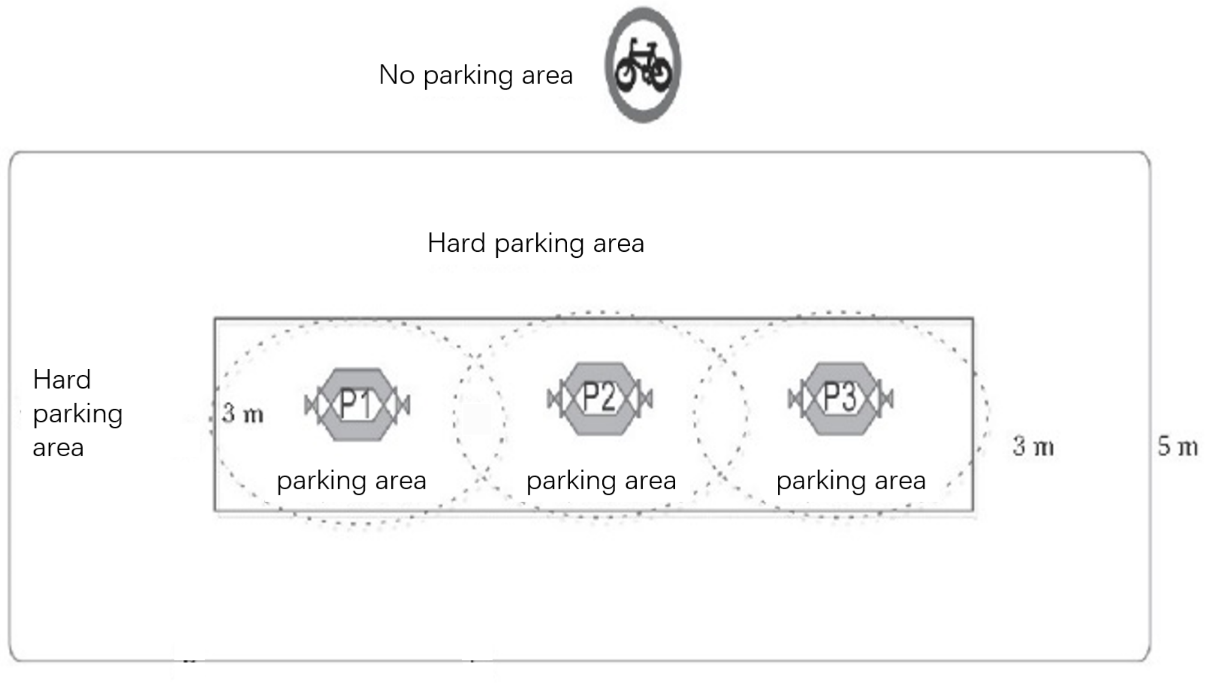

FIGURE 4. Schematic diagram of parking area division

80% of the total number of external damage accidents. The power company will cooperate with the traffic management department to install the positioning system and provide specific solutions for managing large mechanical vehicles. Practice has proven that it is feasible and effective to combine the positioning technology of automobile electronic fence to prevent external damage.

3. **Problem Statement and Solution.** In the research field of protecting overhead transmission lines from external forces, current technical applications cannot completely prevent large mechanical vehicles from causing external damage to the overhead transmission lines. Moreover, the cost for applying the existing technologies, such as video surveillance, is very high. From the perspective of return on investment, whether these technologies are worth investing in can still have more discussion. The method proposed in this paper to prevent external damage to overhead power lines is very practical. It is low cost, high efficiency, and provides functions such as real-time monitoring, effective early warning and instant call. Furthermore, this method can further improve the ability to prevent external damage to overhead power lines caused by large mechanical vehicles.

3.1. **Related technologies of anti-external damage system based on Internet of Things and positioning technology.** After following the above ideas and making improvements, this article proposes an early warning system based on network and intelligent positioning technology to prevent external force damage on overhead power lines. The system has the characteristics of low cost and high confidentiality. The structure of the early warning system based on network and intelligent positioning technology (hereinafter referred to as the system) is shown in figure 5 which includes the following parts:

(a) Beidou satellite navigation system

The newly released China Beidou Navigation Satellite System (”BDS”) which is a

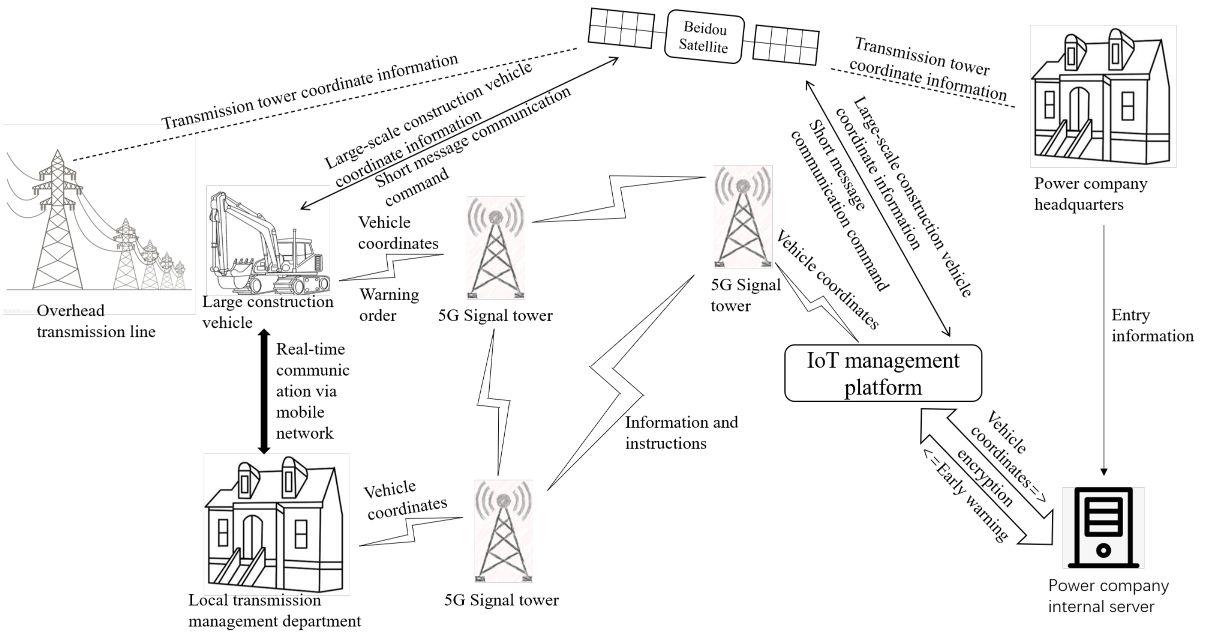

FIGURE 5. Schematic diagram of the structure of the anti-damage system based on positioning technology

high-precision positioning service platform has achieved secondary positioning, and the positioning accuracy has increased to 1.2 meters. On this basis, the Beidou satellite positioning system can accurately locate large mechanical vehicles in real time. China's Beidou satellite positioning system also provides the function of short message service (SMS). In the areas without the coverage of mobile network the function of SMS will greatly improve the effective early warning capability of the early warning system. In the method proposed in this article, the most important step is to install a smart phone with a Beidou satellite positioning receiver chip on a large mechanical vehicle. Usually, we choose to use the driver's smartphone to complete this work. This will enable the IoT platform to easily, quickly and accurately obtain information and location information of large mechanical vehicles.

(b) Internal server of the power grid

The power company's internal server will be controlled by the power company's headquarters and supplemented by blockchain technology to ensure its security and confidentiality [30]. To ensure that messages can be securely transmitted between different entities in a smart grid [31]. The server mainly provides the functions of calculation, storage, information receiving and command sending. It is a high performance and reliable server. In the system proposed in this article, the server needs to store relevant power line information, such as the coordinates of overhead power lines, line voltage levels, line names and numbers. Because such information relates to the security of the power grid. Therefore, it is a state secret and must be stored in accordance with regulations. In addition, the server needs to receive the location information of large machinery and vehicles sent by the IoT platform to determine the risk level. The risk level will be determined by following steps: (i) obtain the position information of the tower closest to the position of the large machinery vehicle (usually two adjacent towers). (ii) Activate the risk level calculation subsystem to input the tower coordinates and the coordinates of the large machinery vehicle. (iii) obtain the result (of risk level). (iv) output the corresponding risk level response instruction. Finally, the server sends the location and response instructions of the large mechanical vehicle to the IoT platform, and then classifies and saves key data.

(c) IoT platform

The IoT platform acts as a bridge in the system proposed in this article. It connects the internal network of the power grid and the public network (such as 3G / 4G / 5G / WIFI / BDS / GPS). Security is one of the major issues in Internet of Things (IoT) research [32]. A secure IoT storage service solution is provided in [33]. This solution can maximize the security of the internal network of the power grid and realize the information interaction function with the public network. The IoT platform proposed in this article can be developed based on a mobile phone application (APP) or WeChat applet. The functions of the IoT platform mainly include the following aspects: (i) Receive positioning information from the public network and send it to the internal server of the power grid after processing information. (ii) Receive response commands from the internal server of the power grid, and then respond according to the content of the commands. The mobile terminal device sends out an alarm after receiving the information. (iii) Through the public network, the location and communication method of large mechanical vehicles send an early warning signal to the local power transmission management department.(iv) The SMS function chip of the Beidou satellite positioning system is used for special circumstances Information transfer.

(d) Terminal equipment and wireless communication module

With the mature BDS chip, more and more smart phone manufacturers begin to carry the chip in their newly launched smart phones. The system uses a smartphone equipped with the aforementioned communication module and navigation chip as the terminal device. When the vehicle driver is equipped with this type of mobile phone, he only needs to install an APP in the mobile phone to access the system to receive warning messages. This can protect the safety of the driver during the construction process. Smart phones also have the functions required by the system, such as positioning, real-time communication, and sound and light alarms.

3.2. **Workflows of the anti-damage system based on Internet of Things and positioning technology.** The process diagram of this system is shown in figure 6. operation steps of the system are as follows:

(a) Divide the risk level and response content of the line according to the protection area of the overhead transmission line.

At present, the voltage levels of overhead transmission lines in China are divided into 6kV, 10kV, 35kV, 110kV, 220kV, 330kV, 500kV and 800kV. According to the safety requirements of the power grid, overhead transmission lines of different voltage levels have different safety distance standards, and the line protection area (the area in two parallel planes formed by the horizontal extension of the edge conductor and perpendicular to the ground) is set according to this standard. The safety distances for different voltages are as follows: 1 10 kV-5 meters; 35 110 kV-10 meters; 154 330 kV -15 meters and 500 kV -20 meters. According to the standard, three risk level areas are defined: line protection area, monitoring work area and hazard warning area. In order to ensure safety and consider the influence of the tower cross arm width on the calculation, the system uses the maximum cross arm width as a parameter in the calculation process. That is, the hazardous area in the system will be defined according to the actual situation, thereby improving the accuracy of early warning.

There are three types of response contents for different risk levels in the system which are described as follows:

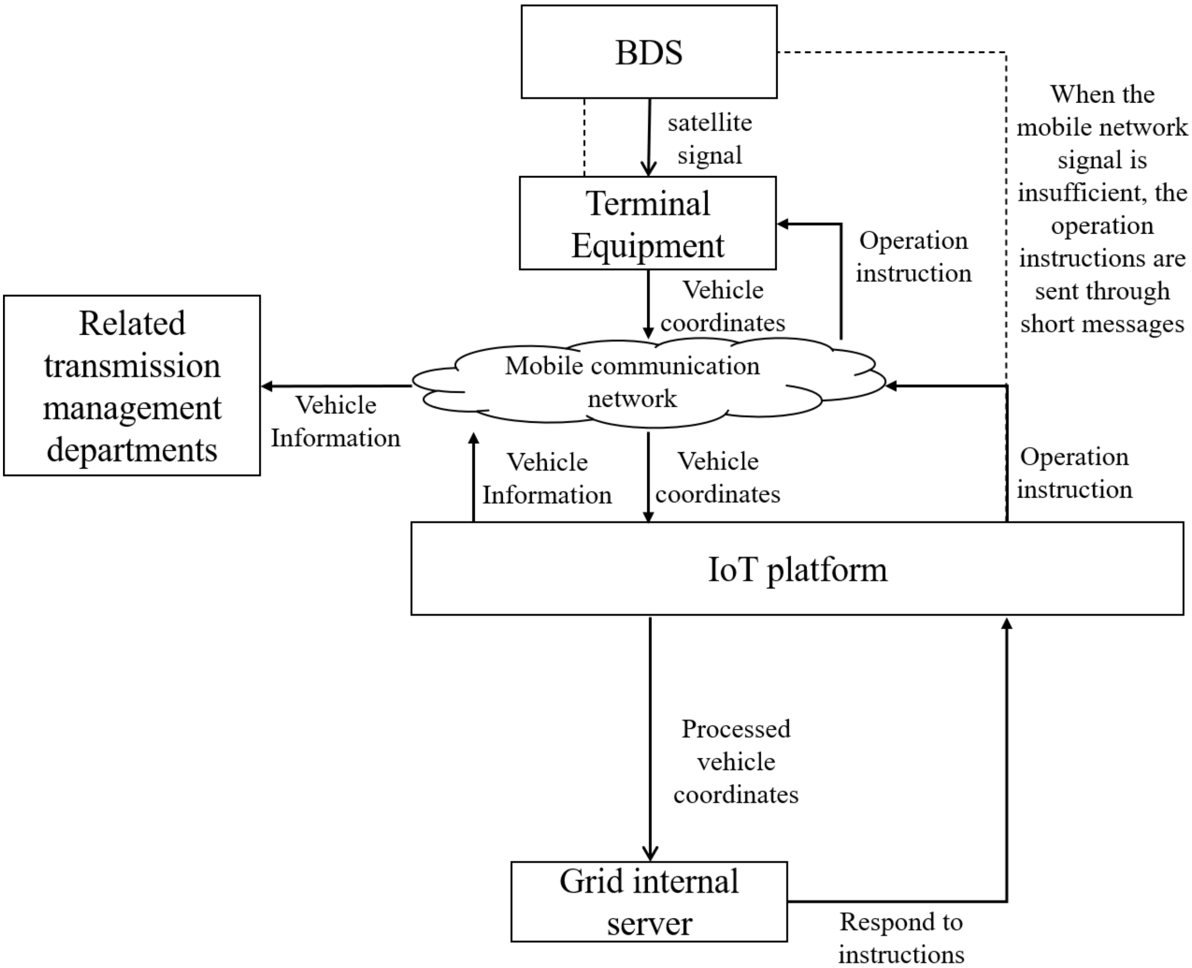

Figure 6. Early warning block diagram of the system against external damage

(i) Level 1 response: When the location of the monitored objects is in the power line protection area, the response will be distributed to three targets: the drivers, the electric power company, and the local management department, respectively. For the drivers, when getting the warning response, they have to immediately stop their works and leave the power line protection area to prevent damage to the power line if they continue their operation on the scene. The electric power company will be notified that an event has been triggered that may cause damages to the power line. The local management department will also receive the warning message which contains the detail information such as the coordinate location of the vehicle entering the line protection area, and the mobile phone number to contact the driver.

(ii) Level 2 response: When the monitored objects are located in the surveillance work area. The drivers of the large mechanical vehicles should be warned: to stop construction immediately and wait for the management to delimit the construction scope. The local management department will also receive the warning message which indicates the location of vehicle entering the monitoring work area, and the contact information to the driver.

(iii) Level 3 response: The location of large mechanical vehicles are in the danger warning zone. The drivers of the large machinery vehicles should be warned: that there are overhead power lines near the vehicle, so please be careful when working.

(b) Obtain the coordinates of the overhead transmission line towers by Beidou satellite

positioning technology and store them in the internal server of the power grid.
At present, the measurement records of the coordinates of the overhead transmission line towers have been kept in every power company in China. Each tower has been tagged a specific number. The collection of all the related data will be stored in the internal server of the power grid for further applications and the security of data.

(c) Beidou satellite positioning technology and mobile network positioning technology can accurately locate large mechanical vehicles. The coordinates are transmitted to the IoT platform, and then the IoT platform will also transmit the data to the internal server of the power grid.

The terminal equipment installed in the large-scale engineering vehicle can locate its position and transmit the position information through the mobile communication network to the system. Currently, the mobile network positioning technology used for target positioning through base stations has been very mature. In [34-35], the positioning function of sensor nodes in wireless sensor networks is mentioned. The smartphone used in this article is also equivalent to a wireless sensor. Therefore, when the satellite positioning signal is weak or no signal, the wireless sensor positioning service provided by the mobile network provider can also be an option for data transmission. In some areas where the signal of the base station signal cannot cover, the Beidou satellite navigation system can be used for positioning. The two positioning system can be complementary and realize the operation of precise positioning. The location information of large mechanical vehicles is encrypted by the IoT platform and then sent to the internal server of the power grid. This process can effectively prevent large mechanical vehicles from being monitored by the power grid.

(d) The internal server of the power grid determines the dangerous area where the large mechanical vehicle is located, and sends the operation instruction to the IoT platform, and the IoT platform will respond to the warning message.

After the internal server of the power grid receives the coordinates of the large mechanical vehicle, the two closest towers will be selected to calculate the dangerous area. And then the risk level will be determined according to the location of the vehicle in the dangerous area. Due to the determined risk level, the responding command will be sent to the IoT platform. After receiving the instruction, the IoT platform will activate the operation for early warning. If the connection between the platform and the monitored object cannot be established, the platform can use the Beidou short message function to send early warning responses to the workers.

(e) After the terminal device receives the instruction manual, it will issue an audible and visual alarm, and the relevant management department will receive the location information of the large mechanical vehicle and the contact information of the terminal device. Such that, the warning process of the system has completed.

4. Boundary delimitation algorithm of early warning recognition area.

4.1. Determine the warning range.

In China's power grid safety regulations, overhead power lines of different voltage levels have different safety distance standards. The volume of the tower will be very different and it will directly affect the warning range. We assume the distance between the edge conductor and the center of the tower is K, and the angle formed by the power line and the latitude is represented as θ. The minimum safe distance is defined as 1.5 times of K. The safe distance for the different voltage level is listed in table 2. Assume that the latitude and longitude coordinates of the two adjacent power towers are $(x_1, y_1), (x_2, y_2)$. The θ can be calculated as the equation (1).

TABLE 2. Safety distance parameter

Voltage level voltage (kV)	Safety distance K distance (m)
10	2.25
35	4.5
110	7.5
220	9.0
330	10.5
500	13.5

$$\theta = \arctan \sqrt{\frac{(y_2 - y_1)^2}{(x_2 - x_1)^2}} \tag{1}$$

The warning range will be based on the center coordinates of two adjacent reference points as the reference point. The standard safety distance is K. It will be set used to calculate the width of the extended range. In fact, there will be some towers around the corner. To eliminate the warning blind zone, the detection area will be expanded in the same direction of the power line, which may cause a warning blind zone. The protection area is formed as shown in figure 7. Figure 8 present the relationships of the protected area, the surveillance area and the warning area.

Taking the 220kV line protection area as an example, the standard safety distance is

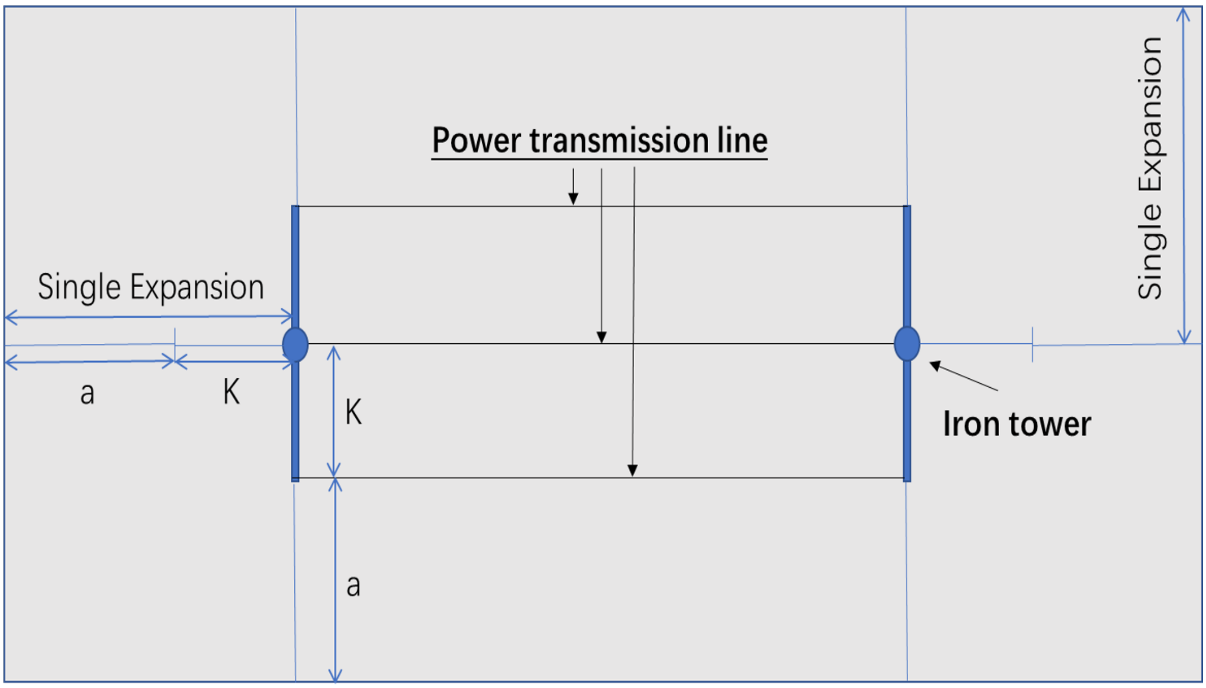

FIGURE 7. Schematic diagram of line protection zone division rules

15 meters, and K is 9 meters. The protected area will be a rectangular area which width

is 48m and the length is the distance of the two towers plus 48m. We can calculate the other two areas as figure 8 presented. Simply, we can present the location of the power

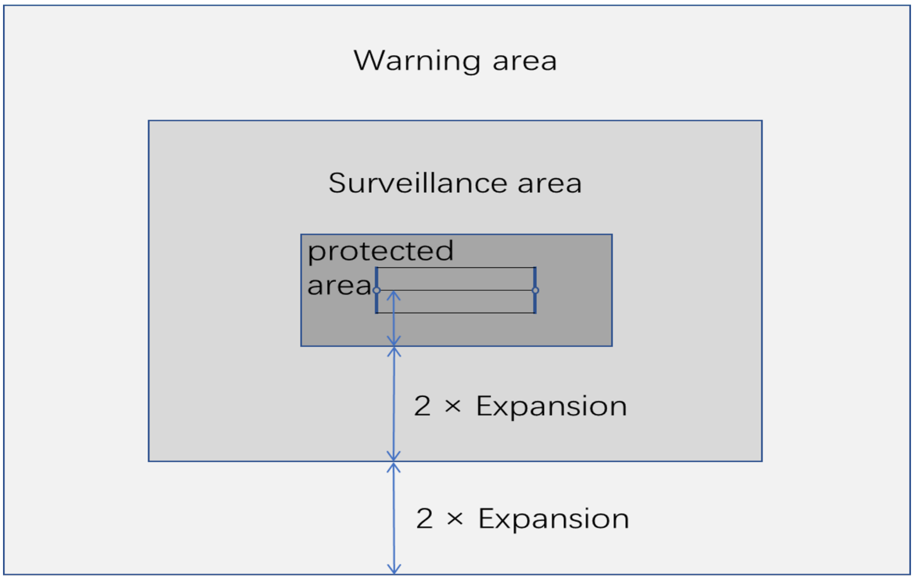

FIGURE 8. Three regional division diagrams

line as the linear equation:

$$y = Ax + B \tag{2}$$

Assume the coordinates of the two towers are (x_1, y_1) and (x_1, y_2). We can obtain A and B from:

$$\begin{cases} y_1 = Ax_1 + B \\ y_2 = Ax_2 + B \end{cases} \tag{3}$$

For the area expansions, the equation for the boundary lines which are parallel to the power line is shown as following:

$$y = Ax + B \pm n\,(a + K) \tag{4}$$

Since the area is rectangular, the slope of the left and right borders of the rectangular area should have the following relationship with A, and can be obtained:

$$A_t \times A = -1 \tag{5}$$

The boundary line which is vertical to the power line can be presented as:

$$y = A_t x + B_t \tag{6}$$

Substitute the coordinates of the tower to obtain B_t.

Assume $x_1 > x_2$, the left and right boundaries of the rectangular area are:

$$y = A_t x_1 + B_t - n\,(a + K) \tag{7}$$

$$y = A_t x_2 + B_t + n\,(a + K) \tag{8}$$

Also need to consider when $A = 0$, $A_t = 1$, and $B_t = 0$.

So far, we determine the boundaries of three different areas mentioned before. Next, we have to consider how to determine which area the large mechanical vehicle is located in. According to the scenario shown in figure 9, we can obtain 4 points (y_1, y_2, y_3, y_4) which are the intersections of the vehicles x line and the four boundary lines of the area. Assume the value of Y axis of the vehicle is y. If the y value is between y_1 and y_2, but also between y_3 and y_4, we can determine that the vehicle is in the protection area, otherwise the vehicle is outside the protection area.

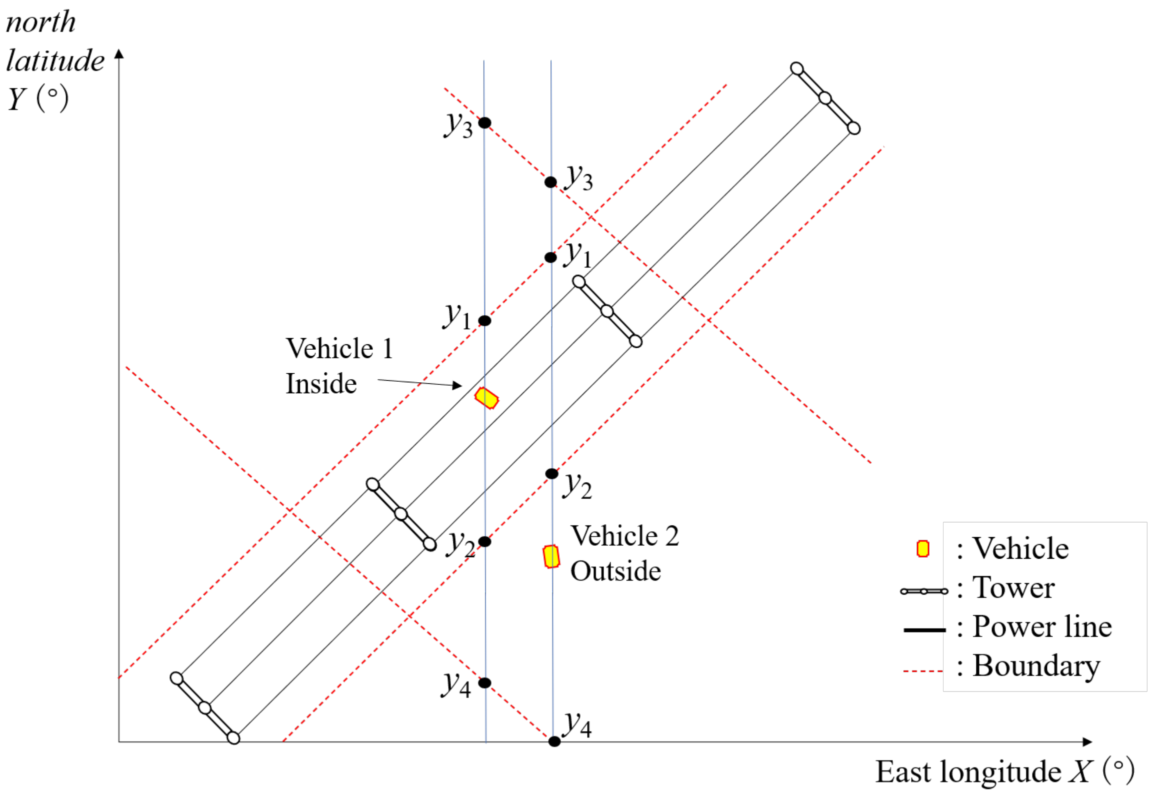

FIGURE 9. Determination scenario for the early warning area of the vehicle

4.2. **Choose the two towers closest to the car.** As mentioned above, the coordinates of the towers are used as reference points for dividing the warning area. In 2017, the total length of domestic elevated transmission lines of 220kV and above has reached 688,000 kilometers, and the total number of transmission towers has exceeded 1 million. It may be difficult to quickly filter out two points that meet the requirements from such a large amount of data. In [36], it also pointed out the problem of high data processing latency in smart grids. We plan to use big data technology and intelligent algorithms to solve this problem. In [37-39], QUATRE algorithm and FMO algorithm are proposed which can improve the performance of data processing. According to these methods, we can quickly select the best tower coordinates from a large number of tower coordinates as a calculation reference.

In addition, this article also proposes a simple and feasible algorithm called the directional blasting algorithm. The procedure is divided into two steps. The first step is to determine a square area with a side length of about 5.55 km centered on the vehicle coordinates. The reason for choosing a square area here is that we can directly use latitude and longitude for calculation. The second step is to explode, that is, to traverse all the towers in the range. The coordinates of the two adjacent towers closest to the vehicle are calculated.

Due to the small amount of experimental data in this paper, the number of poles and towers used for simulation experiments is relatively small. Therefore, only the second step is used in the selection of the tower to calculate the distance between the vehicle and the tower. Then obtain the coordinates of the two adjacent towers closest to the vehicle. The schematic diagram of the traversal method is shown in figure 10.

The formula used to calculate the distance between the vehicle and the tower is as

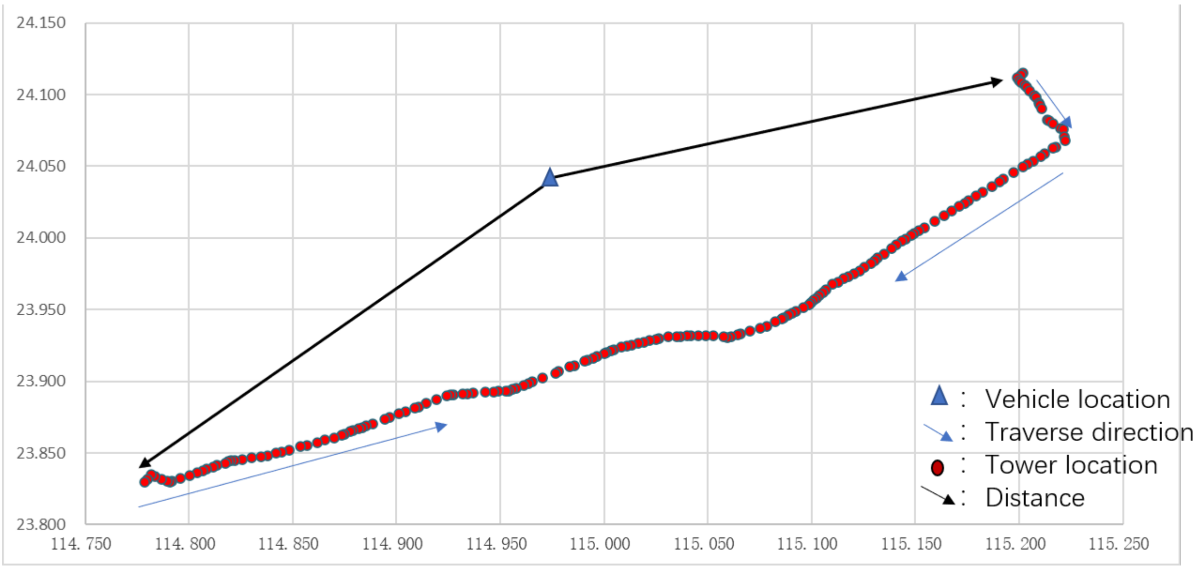

FIGURE 10. Search method diagram

follows, where d is the distance, the vehicle coordinates are (X, Y), and the tower coordinates are (x, y):

$$d = \sqrt{(X - x)^2 + (Y - y)^2} \tag{9}$$

In actual applications, the number of towers is usually numbered in the form of a combination of text and numbers.

In order to simplify the calculation, this article replaces the tower number with a continuous number and uses n_1 and n_2 to represent the tower number in the program. The initial value of n_1 is equal to the number of the tower at the beginning, and the initial value of n_2 is equal to the number of the tower at the end. The code is shown in table 3.

5. **Program Design and Experimental Results.** In this section, we will introduce in detail the experimental demonstration method and data source of the anti-external sabotage system based on network and intelligent positioning technology. And determine the performance of the new method in solving the early warning problem of transmission line damage.

Table 3. Safety distance parameter

initialization: The initial value of n_1, n_2 is equal to the tower numbers at both ends, the vehicle coordinates (X, Y) are input parameters, the tower coordinates (x_1, y_1), (x_2, y_2) are the parameters that vary with the tower numbers n_1, n_2. d_1 and d_2 is the corresponding distance.

Iterative calculation:
while (n_1+1) != n_2:
    $d_1 = \text{sqrt}((X - x_1)^2 + (Y - y_1)^2)$
    $d_2 = \text{sqrt}((X - x_2)^2 + (Y - y_2)^2)$
    if $d_1 > d_2$:
        n_1=n_1+1
        x_1=x_{n_1}
        y_1=y_{n_1}
    else:
        n_2=n_2-1
        x_2=x_{n_2}
        y_2=y_{n_2}

Output: The coordinates of the two towers closest to the vehicle.

In order to better verify the accuracy, reliability of the system, the following experimental procedures were designed:

5.1. **The source of the tower coordinate data set.** The coordinate data of the overhead transmission line used in the experiment comes from a 220kV deactivated line of China Southern Power Grid. This row contains a total of 172 basic tower coordinates. In the experiment, 172 basic tower coordinates are divided into 10 continuous tower coordinate data sets. There are ten groups.

5.2. **Generate random coordinate data sets of large mechanical vehicles.** In the experiment, three sets of random coordinate data sets of large-scale construction vehicles were randomly generated in each section of the route. A total of 90 sets of random vehicle coordinate data were generated, and the number of samples in each group was 100.

Table 4 shows the code segment used to generate random coordinates.

5.3. **Conduct simulation experiments and draw conclusions.** In the simulation, the feasibility, reliability, and speed of the calculation method proposed in this paper are mainly examed. The communication module, IoT platform, mobile terminal application, and Beidou navigation system involved in this system are all mature technologies that have been widely used in the civilian market. Therefore, this article assumes that the performance of the corresponding software and equipment is completely reliable.

Under this condition, the response accuracy, reliability, and calculation speed of the system are tested. The program flow chart used in the test is shown in figure 11.

TABLE 4. Safety distance parameter

initialization:
The initial values of a, b, c, and d are respectively equal to the maximum longitude, minimum longitude, maximum latitude, and minimum latitude in the coordinate data set of the pole and tower.

Generate a random coordinate data set:

```
1: i=0
2:     r=[(random(a,b),random(c,d)) in range(100)]
3:     for s in r:
4:         print(Large construction vehicle coordinate: s)
5:         i=i+1
```

5.4. **Experimental process and results.** The following is the presentation of the first set of experimental data and experimental results.

(a) The image of the power line tower route map in the coordinate system

For example, table 5 shows the first set of tower coordinate data, and figure 12 is its image in the latitude and longitude coordinate system. The images in the latitude and longitude coordinate system corresponding to the ten data sets used in this article are shown in figure 13.

(b) Random coordinate data set of large construction vehicles

TABLE 5. The first set of tower coordinate data sets

Tower number	Longitude	Latitude
1	115.2017745971670	24.1147777779897
2	115.2010574340820	24.1139722220103
3	115.1990280151360	24.1117499997881
4	115.2000808715820	24.1101388888889
5	115.2010574340820	24.1086666668786
6	115.2026672363280	24.1062500000000
7	115.2034149169920	24.1051666667726
8	115.2049179077140	24.1028611111641
9	115.2071685791010	24.0995277775659
10	115.2081146240230	24.0980833329095
11	115.2094726562500	24.0941388893127
12	115.2099685668940	24.0927222220103
13	115.2109756469720	24.0899722221163
14	115.2136077880850	24.0823055553436
15	115.2144470214840	24.0816111108992
16	115.2160797119140	24.0800277773539
17	115.2199707031250	24.0766944440206

Within the range of each group of line poles and towers, three sets of random coordinate data sets of vehicles are generated randomly, which are the test data sets.

(c) Test Results

Among them, the red scattered point indicates that the vehicle is located in the line protection zone, the yellow scattered point indicates that the vehicle is located in the monitoring work area, the green scattered point indicates that the vehicle is located in

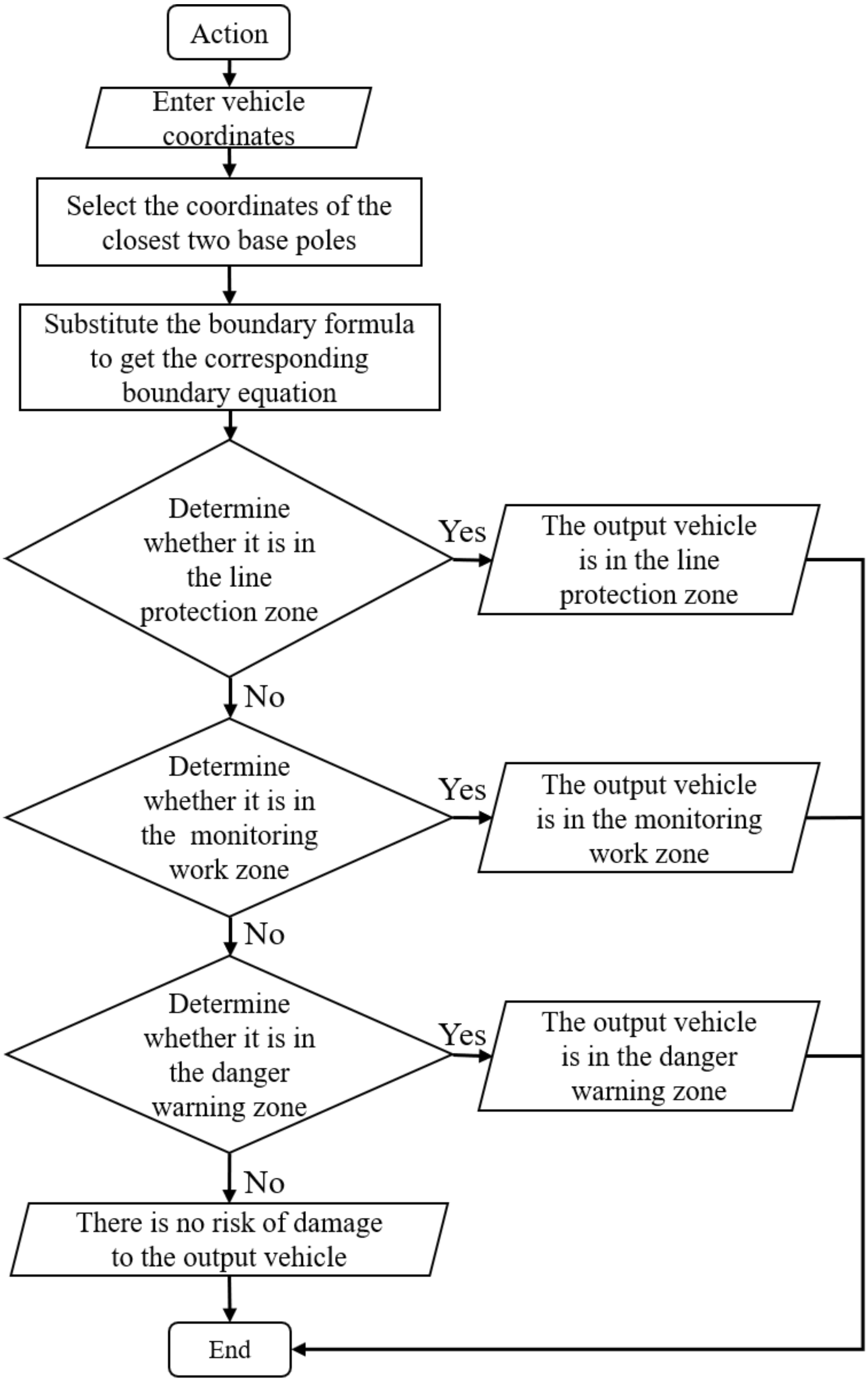

Figure 11. Flow chart of early warning response procedure for preventing external damage

the danger warning zone, and the blue scattered point indicates that the vehicle has no risk of external damage. The test results of the 1st-10th sets are shown in figure 14-23.

(d) Analysis of simulation experiment results

After running all the test sets, the method proposed in this paper can send the early warning alarm on time to prevent damage from external forces and fully meets the predetermined target. In a total of 3000 random vehicle coordinates in ten groups, the missed

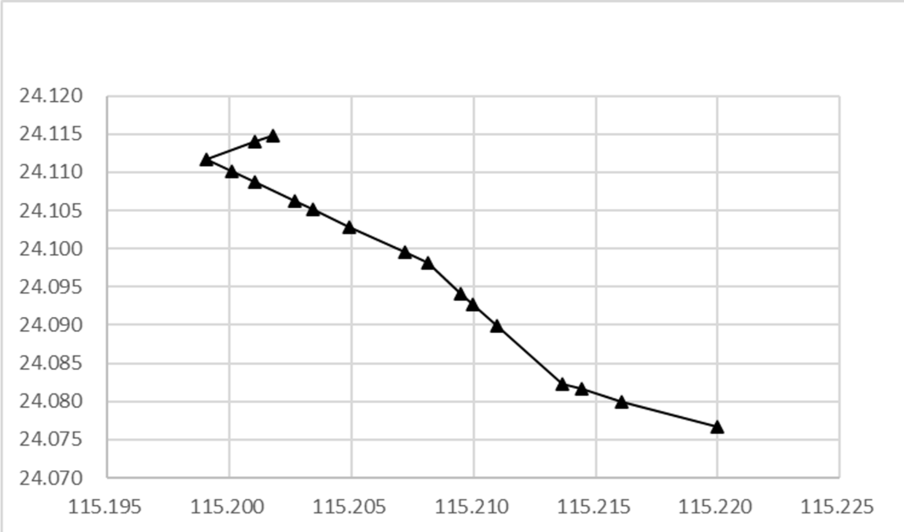

FIGURE 12. The first group of tower coordinate data

alarm rate of the program is 0, and the false alarm rate is 0.1%. The average time used for each test is 0.031965852s.

From the experimental result, it shows that the protection of the transmission line from damage based on the positioning technology proposed in this article is extremely reliable, extremely accurate, and extremely fast in the calculation. The performance fully meets the design requirements in the simulation experiment environment.

6. **Conclusions.** The early warning system is proposed to prevent external force damage to overhead transmission lines. According to our simulations, the system can get reliable responses based on the location of the monitored objects. Compared with other methods, such as image recognition, using the technology with accurate positioning technique can arise the accuracy of detection which can improve the reliability of the prevention system. In our scenario, we only take the transmission line with the voltage level of 220kV. In fact, in many cases the power lines with multiple voltage levels are across in a narrow area. For complex scenarios, our proposed method still need further examined. With the help of big data analysis and intelligent optimization algorithms, the searching process for the qualified reference towers coordinates can be further improved. In this article, only two-dimensional plane coordinates are considered. In the future, the method can be extended to three-dimensional scenarios to make the division of hazardous area more precise and reasonable. Similarly, this method can also solve the problem of protecting underground cables from external damage. But the underground location involves depth, so a 3D solution needs to be added. In [40-41], a long topology routing protocol and scheduling scheme suitable for underground wireless sensor networks are proposed. This brings new solutions for future underground cables to prevent external damage.

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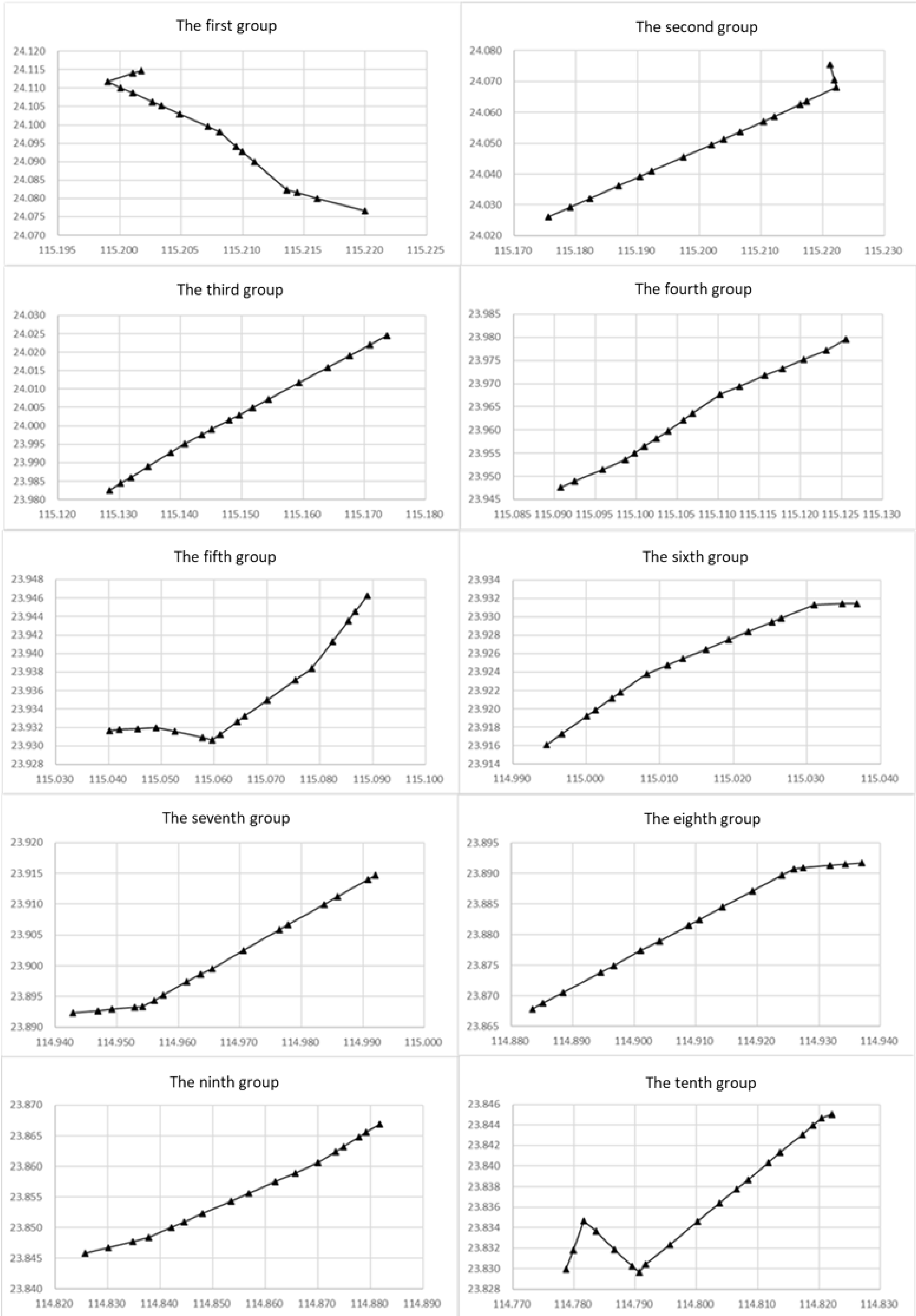

FIGURE 13. The images of ten sets of data

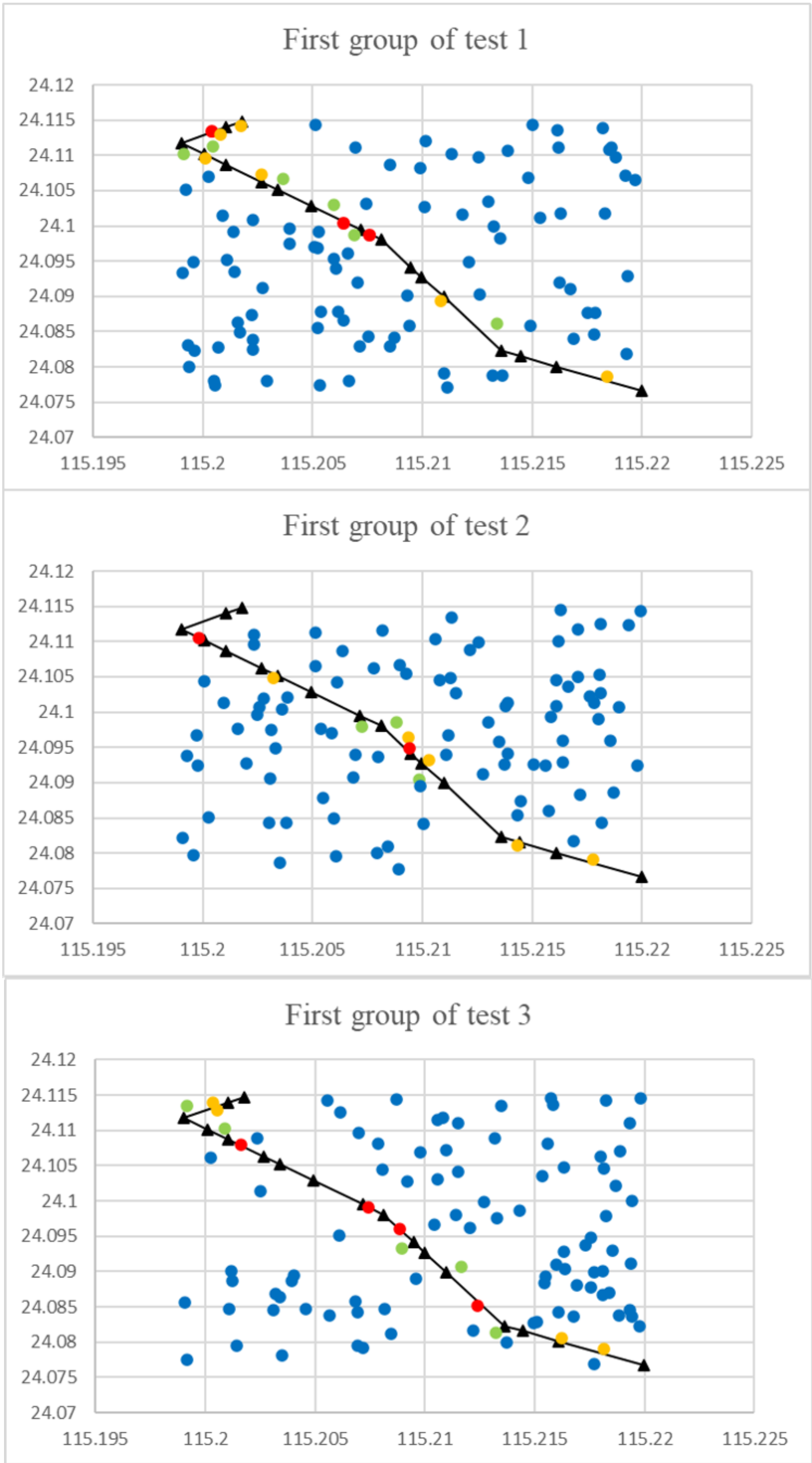

FIGURE 14. The test results of the first set

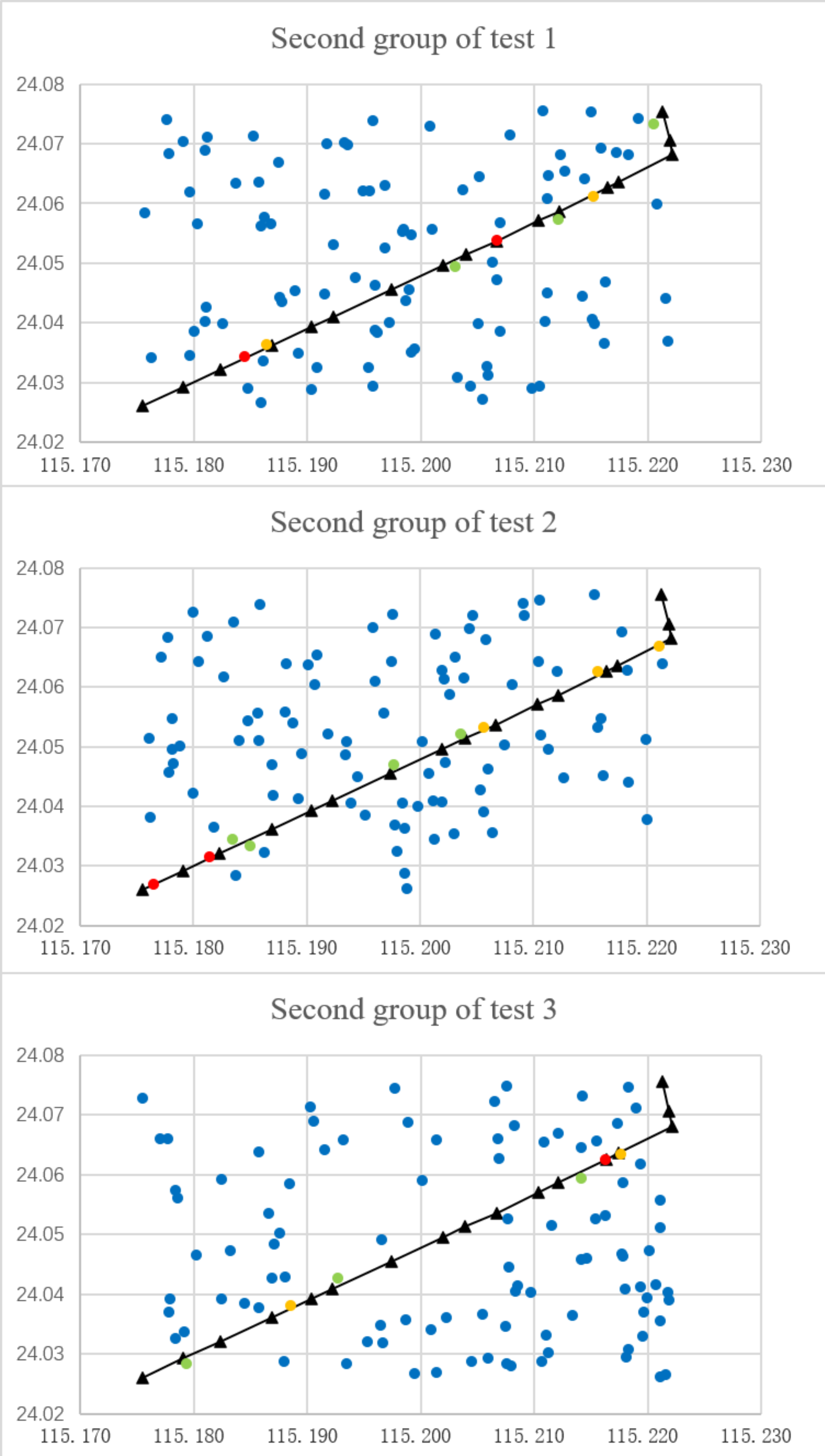

FIGURE 15. The test results of the second set

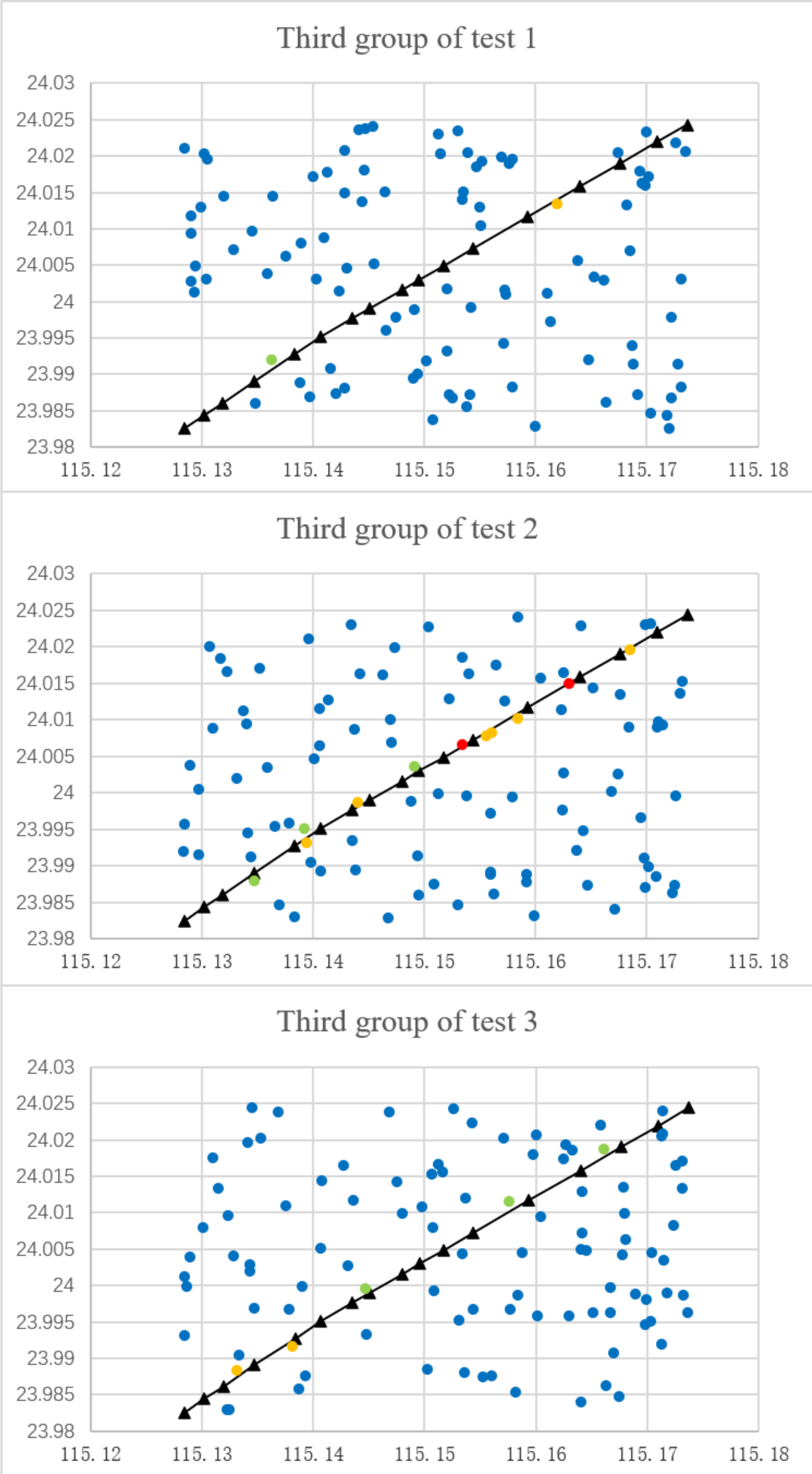

FIGURE 16. The test results of the third set

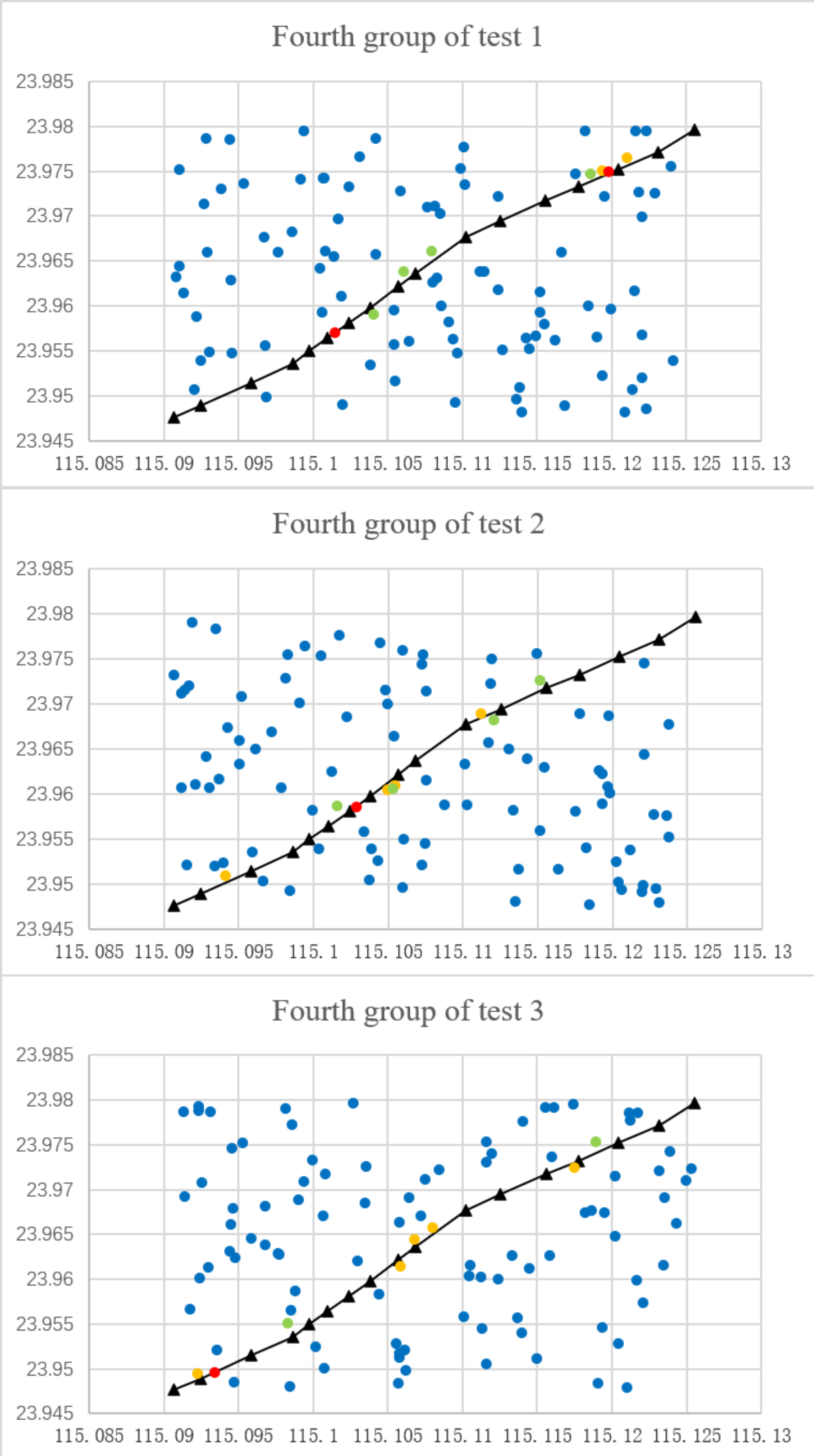

FIGURE 17. The test results of the fourth set

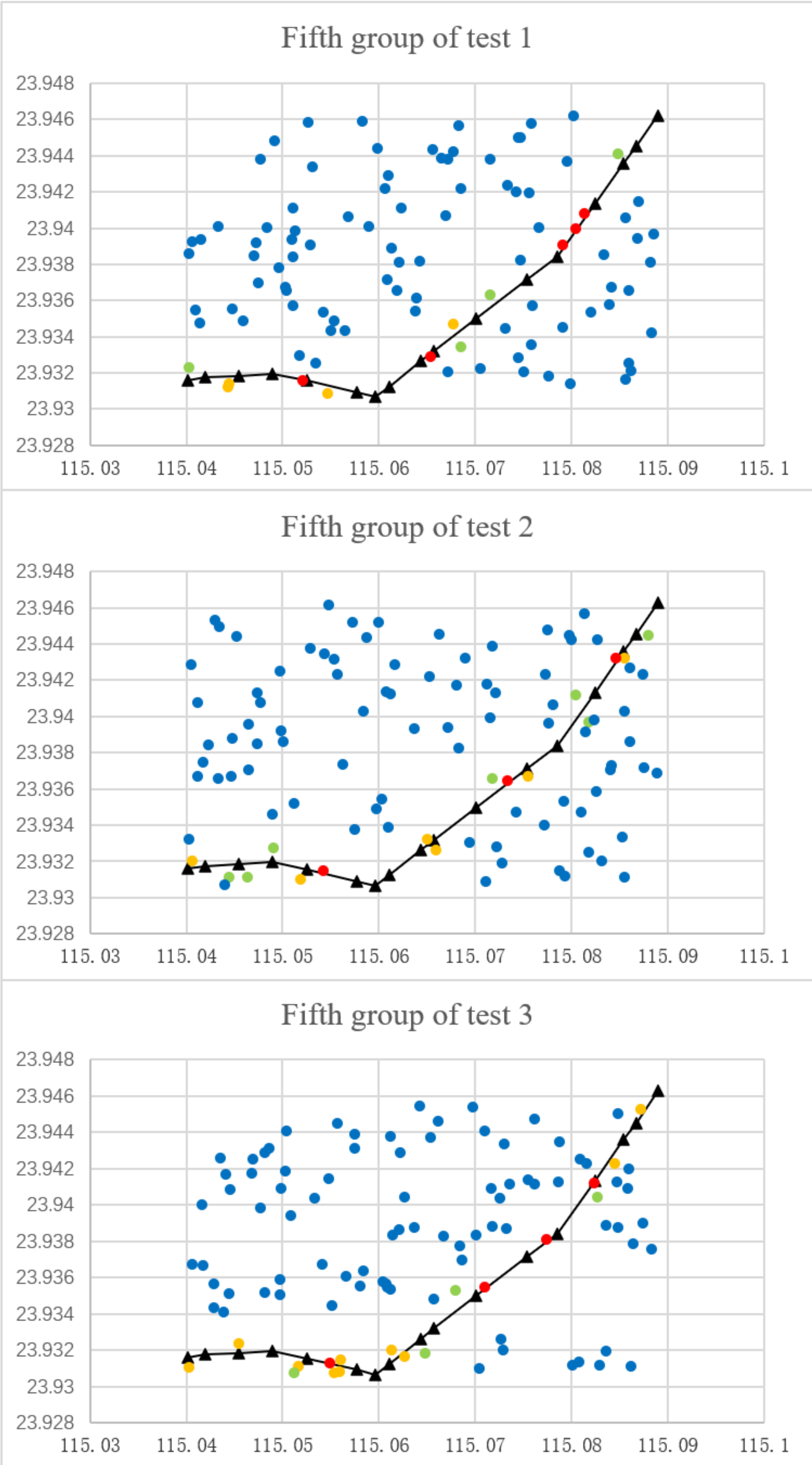

Figure 18. The test results of the fifth set

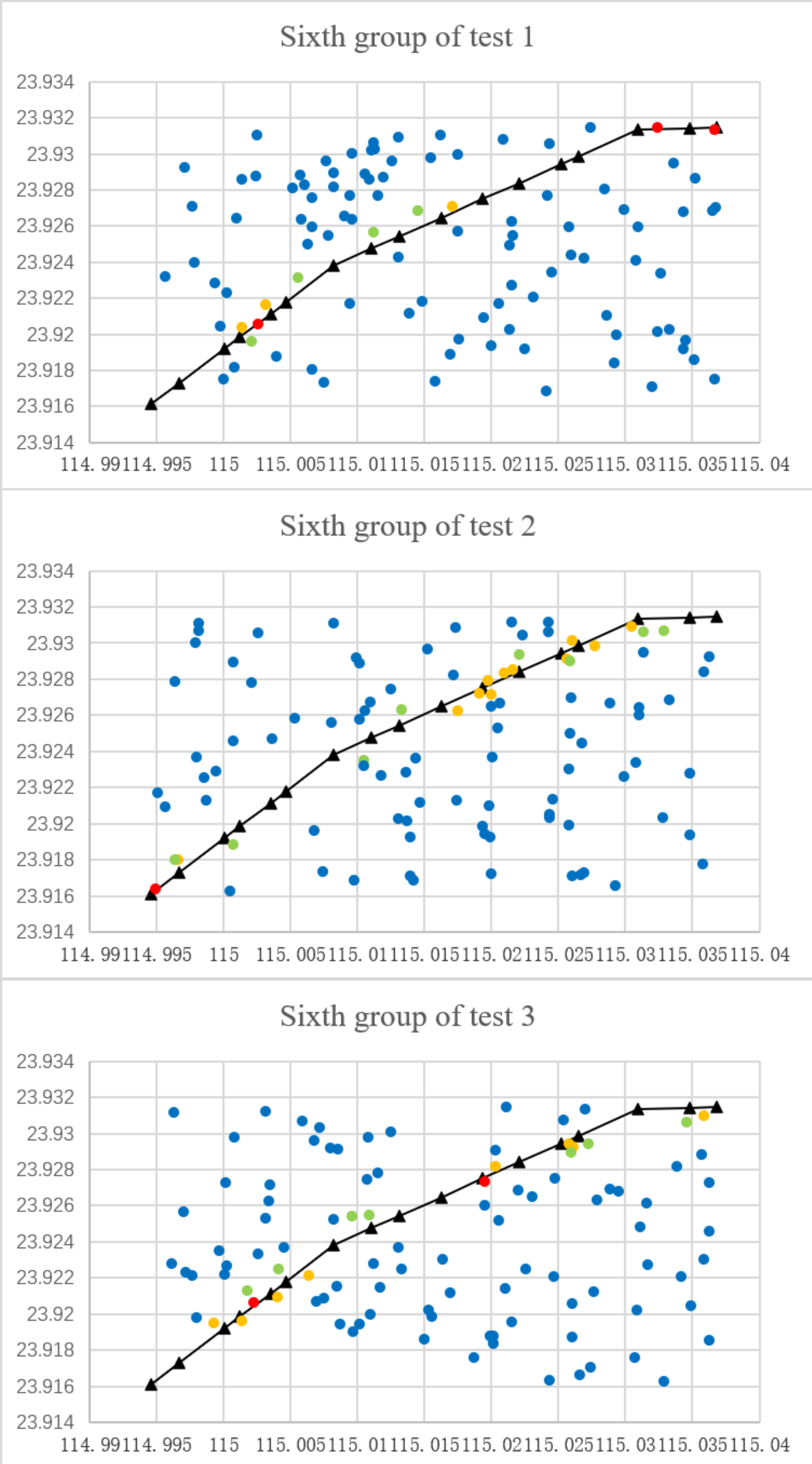

FIGURE 19. The test results of the sixth set

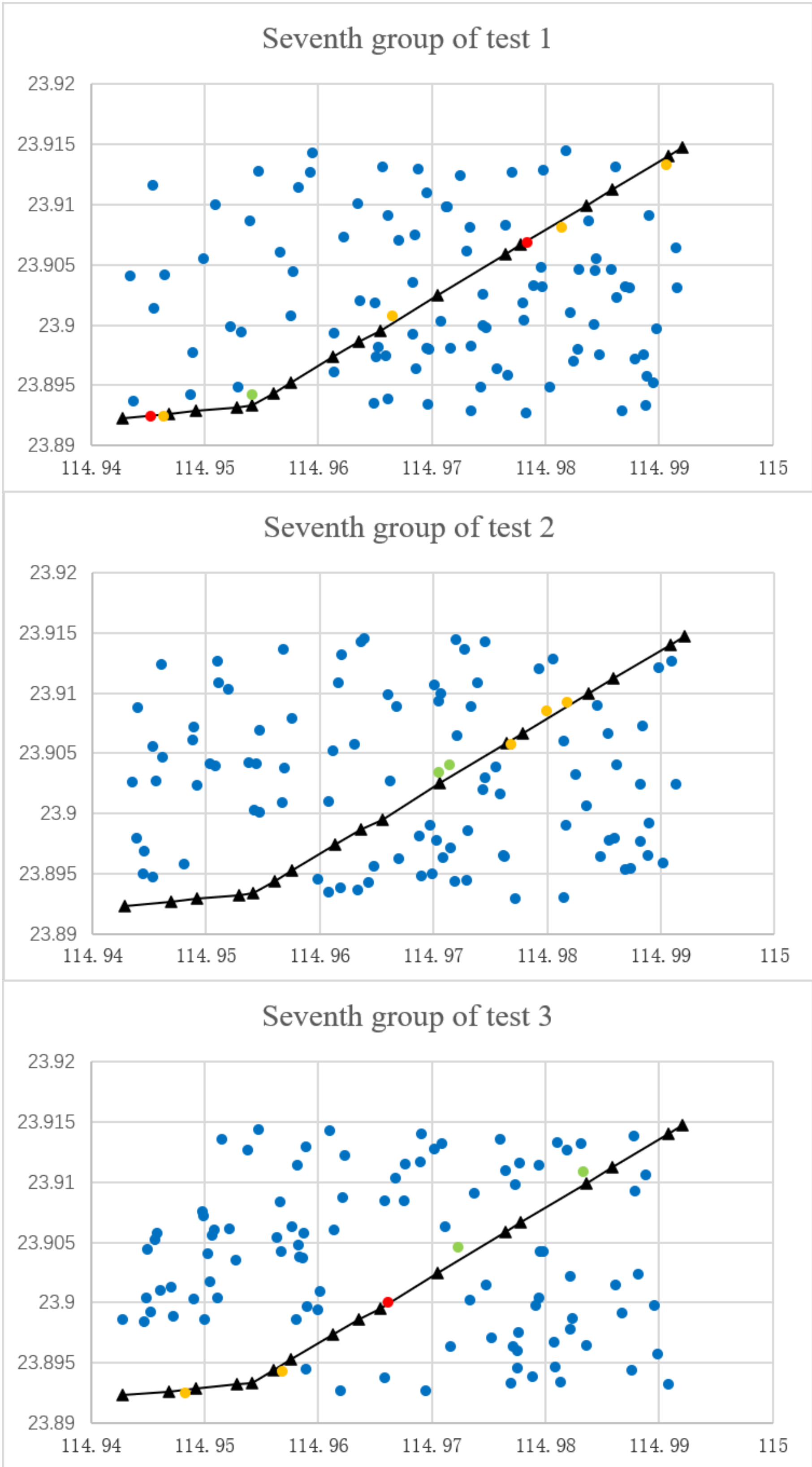

FIGURE 20. The test results of the seventh set

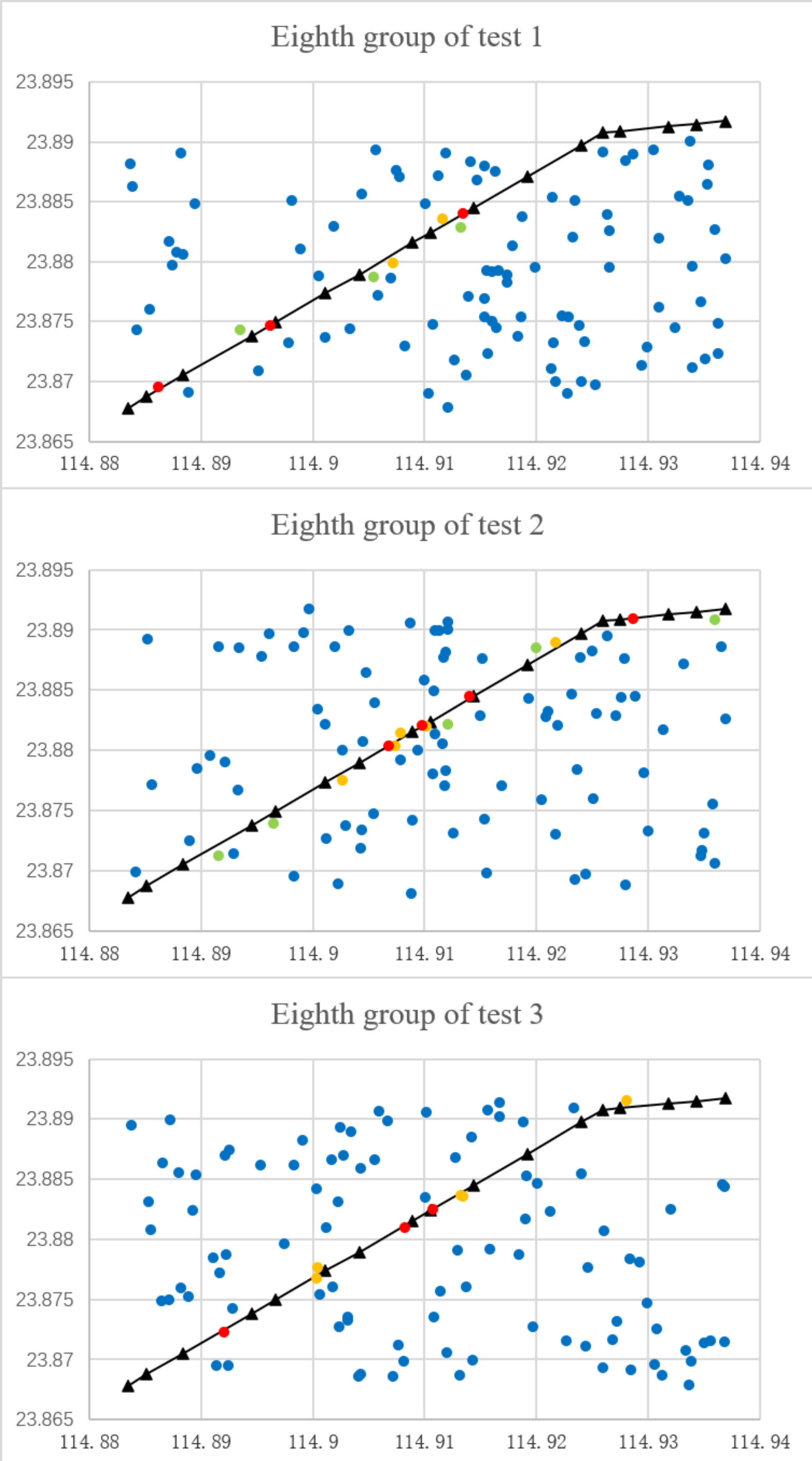

FIGURE 21. The test results of the eighth set

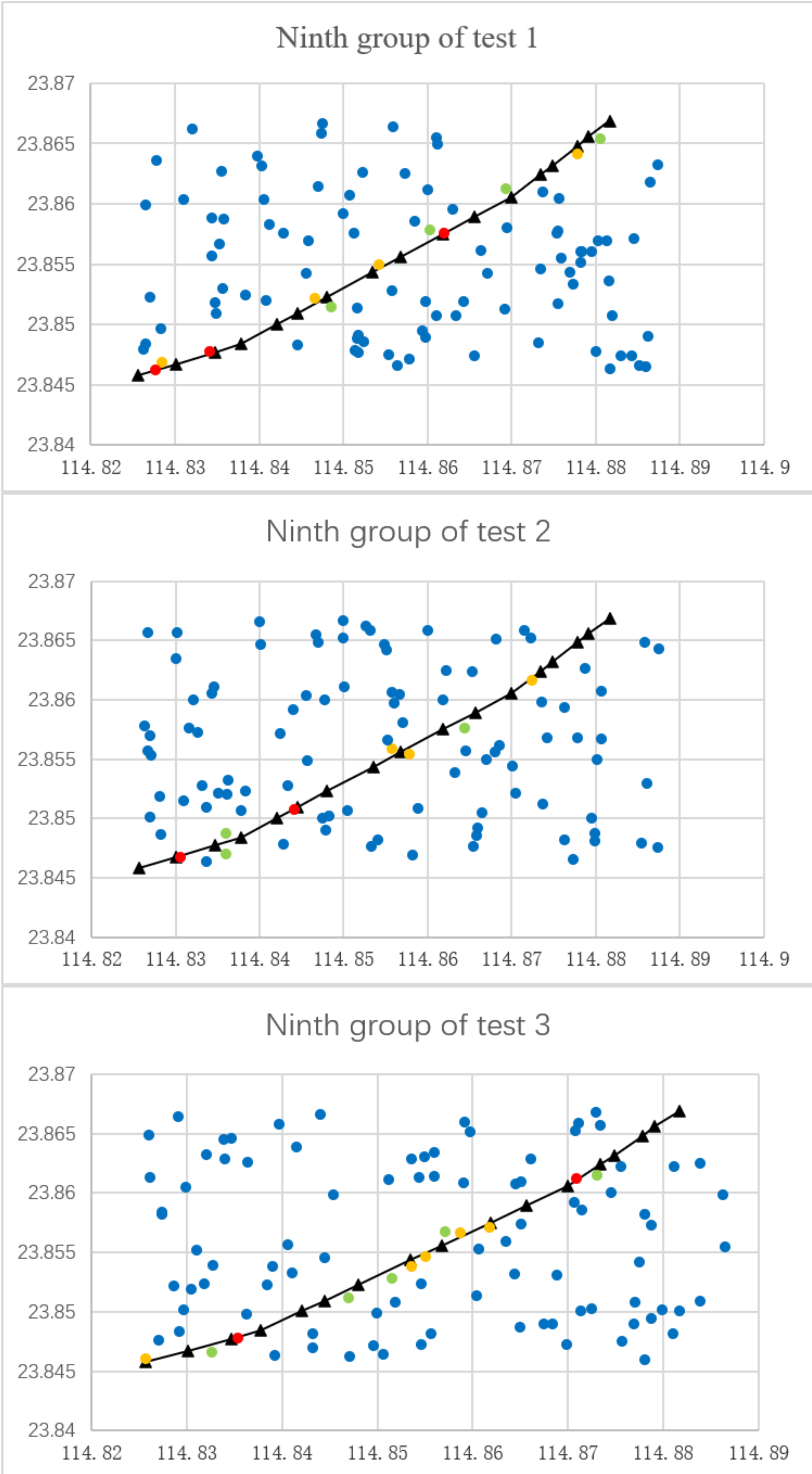

FIGURE 22. The test results of the ninth set

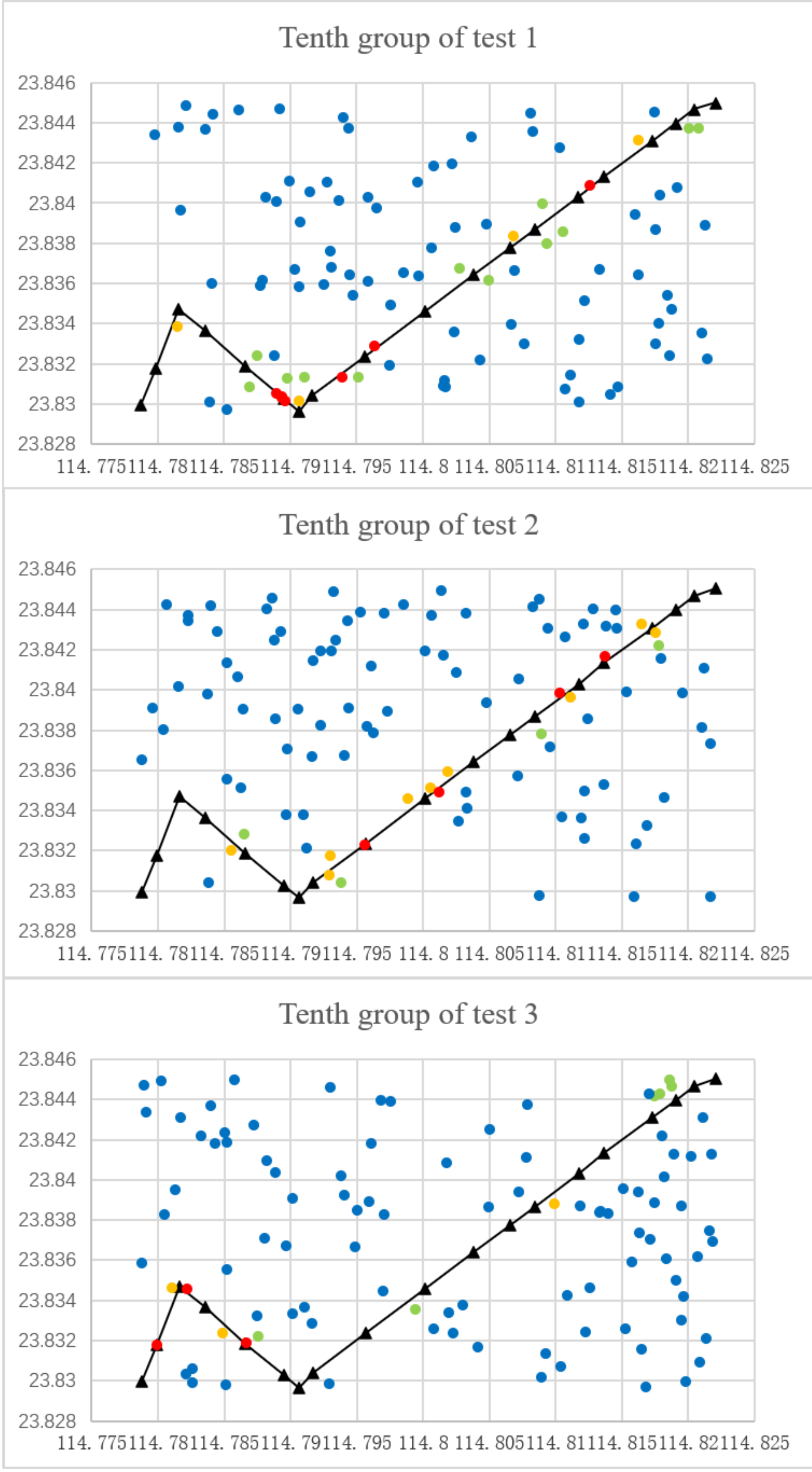

Figure 23. The test results of the tenth set

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