Hazard warning design of intelligent safety helmet based on BIM technology joint positioning

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Abstract. Nowadays, construction site engineering safety accidents occur frequently, and there are problems such as unsafe equipment and equipment, management defects, and improper operation of personnel. On the construction site, workers wear safety helmets as required, but fall accidents still occur due to problems such as lack of concentration, irregular construction operations, and unreasonable multi-process three-dimensional cross-operation. with the development of smart construction sites, traditional safety helmets cannot be combined with smart construction site management. Therefore, this paper designs a safety helmet that not only has all the basic functions of traditional safety helmets, but also adds 3D positioning function and safety warning function on this basis. Combine the helmet with the intelligent management platform, use BIM (Building Information Modeling) technology and site CAD planning map technology, and use NDT algorithm preprocess to obtain floor plane information; then improve the Kalman filtering algorithm (ESKF), the positioning information output by helmet-related hardware equipment is secondary processing with Python, the specific plane coordinates and floor height are obtained, and transmitted to Revit software (the most widely used software in China's construction BIM system) for character modeling. Finally, the obtained worker plane position combined with BIM technology is used to obtain three-dimensional location information on the intelligent management platform.

Keywords: Smart safety helmet; Hazard warning; BIM technology; Intelligent management platform

1 Introduction

With the progress and development of science and technology, helmets on the market are no longer limited to traditional functions. There are new helmets with integrated protection, real-time monitoring and emergency communication [1]. Wang Zhaojun et al. [2] developed an intelligent helmet equipped with automatic information collection, multifunctional positioning monitoring and remote signal transmission, but its positioning accuracy was not high; Cao Yu et al. used Beidou navigation satellites to assess the environmental safety of workers [3]. However, in underground exploration areas, satellite positioning signals were weak, and workers could not obtain their accurate positions

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if they were in danger. At present, the development of precision positioning technology is complicated and diverse. The current positioning system and inertial navigation system have obtained a good positioning effect [4]. However, the real-time positioning technology used for the actual movement of workers is less studied in the current research field. This paper will optimize the new positioning technology applicable to the helmet, so that the positioning is more accurate, and the danger judgment alarm is more perfect. Since the 1990s, 3D cloud electronic maps have been effectively used in many cities across the country. At present, 3D reconstruction modeling of digital maps is mainly conducted through CAD technology based on different data sources, so as to generate 3D digital maps. Although OpenGL technology pays attention to the establishment and development of graphics, it lacks the analysis function required in GIS research and cannot conduct multi-dimensional modeling through GIS and other technologies [5]. By combining CAD technology with 3D cloud electronic map, this paper proposes a site map with combined positioning display for the subsequent platform presentation.

Therefore, this paper combines the positioning method of three-dimensional point cloud map and NDT algorithm with BIM technology to develop a software with real-time positioning technology and simulation presentation. This software can conduct real-time positioning of the wearer through the helmet, timely grasp the position of the wearer, and record the path of the wearer. If the wearer is near a dangerous area, The helmet gives a remote alarm based on its location. This function makes up for the shortage of safety helmets in the intelligent field of construction site, and also increases the safety of helmets and reduces the occurrence of safety accidents.

2 Intelligent safety helmet design

2.1 Construction of site map model

In actual operations, long time operation will lead to workers fatigue, thus unable to concentrate, prone to safety accidents, the traditional safety hat cannot make any monitoring and alarm for the safety of workers. Based on the existing research, this paper has mastered the indoor precision positioning technology and developed a set of management platform system combining BIM technology and indoor positioning technology to obtain the location information of workers in real time and give an alarm when workers step into dangerous working areas.

The intelligent safety helmet and platform warning system first create a site map, conduct floor infrared scanning on workers to determine their specific floors, then use radar plane scanning to determine the specific plane coordinates, and the helmet will initially process the data. During the whole construction process, due to the dynamics and uncertainty of the whole construction process, the intelligent management platform will continuously update the height and plane positioning data while continuously monitoring, thus refreshing the movement trajectory of workers.

In this paper, a combination of three-dimensional cloud map, infrared sensor and information memory chip is adopted to obtain the plane information and height information of workers located in the building, so as to achieve real-time positioning of workers at any location on the site. The combination positioning is composed of three parts:

(a). Site map: It needs to be constructed in advance. Workers' positioning information is output from the site map, which is the main tool for background staff to observe.

(b). Workers' plane positioning data: the data is obtained from the helmet worn by the workers;

(c). Workers' height positioning data: Infrared sensors at key locations of the building scan the helmet and transmit the workers' information to the intelligent management platform.

2.2 Intelligent safety helmet system and platform early warning design

Firstly, the site map generated by the three-dimensional cloud map is used to number all areas, buildings and floors in the site map according to the format of district, building and floor. Finally, the compiled information is connected with the constructed map to get the 3D site map. At the same time, the added BIM model is divided into areas of danger and non-danger, and the intelligent safety helmet will give alarm according to the result of the danger judgment. The site map integrates the information data of BIM model for the observation of background management personnel.

The intelligent management platform combines the floor plan data of workers with the floor data of buildings and outputs the results to the site map. The supervision work of the intelligent management platform takes platform supervision as the primary method and human supervision as the secondary method to reduce the probability of site safety accidents.

The design of site intelligent safety helmet system is divided into five parts: creating site map, height coordinate positioning, plane coordinate positioning, intelligent management platform and danger warning. The five parts follow the sequence to achieve model building, data information collection, processing, storage, update, data information three-dimensional display and other functions. Figure 1 shows the design of intelligent safety helmet system.

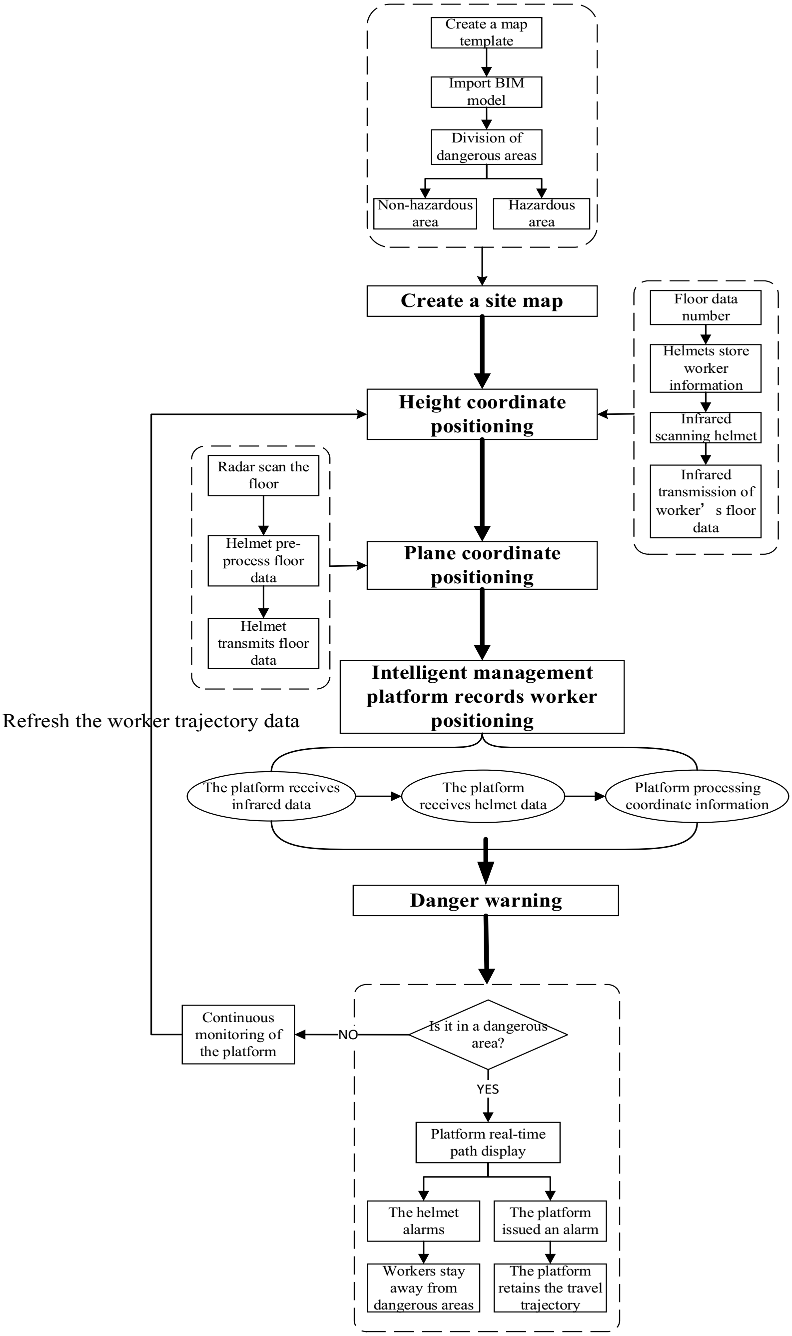

Fig. 1. Design drawing of the smart safety helmet system.

3 Floor height positioning design

3.1 Information acquisition of floor infrared sensor

In this paper, the combination of infrared induction and personal information storage method to realize the height and plane positioning of workers. The infrared sensor has the functions of scanning, processing and sending. It captures the infrared radiation energy emitted by the workers themselves on the infrared sensor and optical imaging objective lens and reflects it on the photosensitive element of the infrared detector [6]. First, the map and helmet number were constructed, and then sensors were installed at key points such as stair landing and intermediate landing. In order to avoid the multi-section information error caused by the simultaneous connection and transmission of multiple floors when the helmet sends the floor information, this paper uses the infrared sensor to send information, which reduces the error and saves the cost.

The smart helmet is equipped with a chip that stores personal information, which will be recorded for each worker. Personal information includes name, age, sex, height, weight, occupation, personal telephone number and other information. Loaded with corresponding helmet of personal information to workers, workers for the first time through sensors, infrared sensors is induced to the workers wearing helmets. Meanwhile, the helmet's information memory chip sends the worker's personal information to an infrared sensor, which sends the received personal information to a smart management platform.

3.2 Intelligent management platform information processing

The intelligent management platform will receive two parts of information. One is the personal information sent by the infrared sensor. The second is the floor plan information sent by the worker's helmet. For the processing of infrared information, the intelligent management platform only calculates the latest information sent by the infrared sensor equipment on each floor, so as to obtain the specific height and position of the workers. When workers move on different floors, the platform, after receiving the latest data of workers passing through floors, will automatically eliminate the previous data, reduce data redundancy, and only retain the information of the latest floor. The smart management platform only displays the information of the latest floor where the workers live, realizing the goal of positioning the workers' floor height. The intelligent management platform has the functions of attendance management, path display, violation inquiry, dynamic management and so on. Figure 2 shows the intelligent management platform system.

Fig. 2. Intelligent management platform system.

4 Floor plane positioning design

4.1 NDT algorithm model sitioning tables

The laser radar, information memory chip, CPU, GPU chip and other hardware are installed in the smart helmet. First, the lidar scans the floor plan; Secondly, the information memory chip, CPU and GPU chip preprocess the floor data, and then the helmet sends the data to the background; Finally, the background calculates the workers' floor data.

The NDT algorithm used in this paper belongs to the laser point matching algorithm, which is a scanning registration algorithm based on mathematical characteristics. Among them, in 2016, Hyunki Hong and B.H. Lee [7] proposed to convert the reference point cloud into a disk distribution suitable for the point cloud structure to improve the registration accuracy of the NDT algorithm. and the other is ICP algorithm based on points [8]. Firstly, the position of the person in the 3D grid (NDT cuts the space into small rectangular blocks, also known as 3D grid) is converted into a continuous differentiable probability distribution function, that is, the sampled position of the reference person and the position of the person to be matched is converted into the probability distribution of the position of the three-dimensional space points in the grid, and expressed with a normal distribution. After that, the

4.2 NDT algorithm information processing

The general process of three-dimensional point cloud matching by NDT algorithm is described as follows [9] .

Step 1: Divide the floor space into 3D grids and calculate the mean μa and covariance E_a of each grid:

$$\mu_a = \frac{1}{m}\sum_{b=1}^{m} X_{ab} \tag{1}$$

$$E_a = \frac{1}{m-1}\sum_{b=1}^{m}(X_{ab} - \mu_a)(X_{ab} - \mu_a)^T \tag{2}$$

In the formula, m is the number of three-dimensional point cloud points in the a cube grid; Xab is the bth point in the a cube grid.

Step 2: Represent the transformation parameters between set A (point convergence) by k, assign initial value to k through the odometer data or initialize k into the identity matrix, transform all points in set A to be registered according to transformation T, and convert to the cube grid of reference A, thus obtaining A new A: $X'_{ab} = T(X_{ab}, K)$ calculates the probability of new A falling in reference A (That is, the degree of overlap between A to be registration and reference A after transformation.) according to the following formula, and adds the calculated probability density of all cube grids to obtain the NDT registration score [10] .

$$p(X'_{ab}) \sim exp\,(-\frac{(X'_{ab}-\mu_a)^T E_a^{-1}(X'_{ab}-\mu_a)}{2} \tag{3}$$

Step 3: Newton optimization algorithm is used to optimize the registration score of NDT, and the best transformation parameter k is obtained to maximize the registration score.

$$S = \sum_a exp\,(-\frac{(X'_{ab}-\mu_a)^T E_a^{-1}(X_{ab}^{-1}-\mu_a)}{2}) \tag{4}$$

When workers wear helmets and enter the floor plane through the elevator or stairs, the laser radar on the helmet first starts to scan the floor plane space. By using the NDT algorithm, the floor plane space is divided into several small rectangular blocks. According to the principle of take up, do not take down, take left, do not take right, calculate the mean and covariance of each small rectangular block. Secondly, according to the NDT algorithm, the small square overlapped with the workers in the space is calculated, and then the irrelevant small square is eliminated.

5 Joint positioning design based on BIM technology

5.1 Joint positioning design process and principle

The site map constructed in advance is embedded into the smart management platform, and combined with the BIM model of specific floors to present the panoramic virtual scene of the site. Finally, the data is transmitted to the smart management platform through the site hardware equipment, and the latest floor information corresponding to the workers is transmitted back to the smart management platform according to the detection signal of the infrared sensor equipment on the floor. Obtain transmitted back floor information and display the corresponding floor plan, output workers in the height. Figure 3 shows the flow chart of helmet function joint design in this paper.

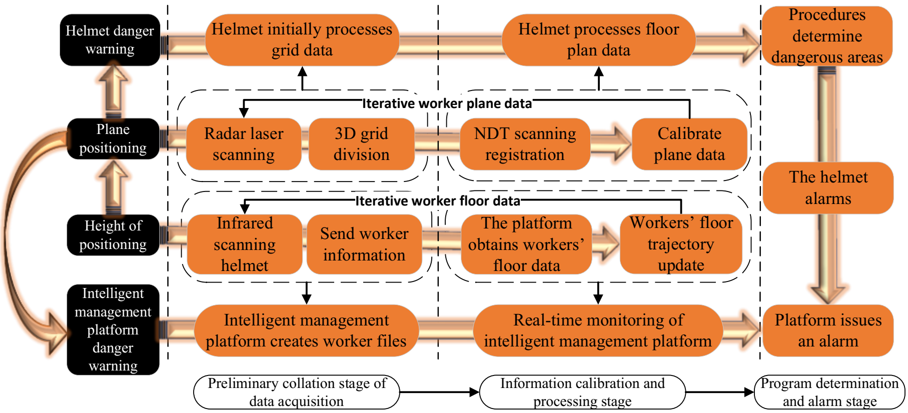

Fig. 3. Helmet design function flow chart.

The registration results of NDT points of the plane coordinate positioning hardware are transmitted to the intelligent management platform, and the specific horizontal coordinate X and vertical coordinate Y of workers are obtained. The intelligent management platform integrates the floors with X and Y coordinates, obtains the layers, X coordinates and Y coordinates of workers, and sends them to the Python program for risk determination. Figure 4 shows the flowchart of coordinate joint representation.

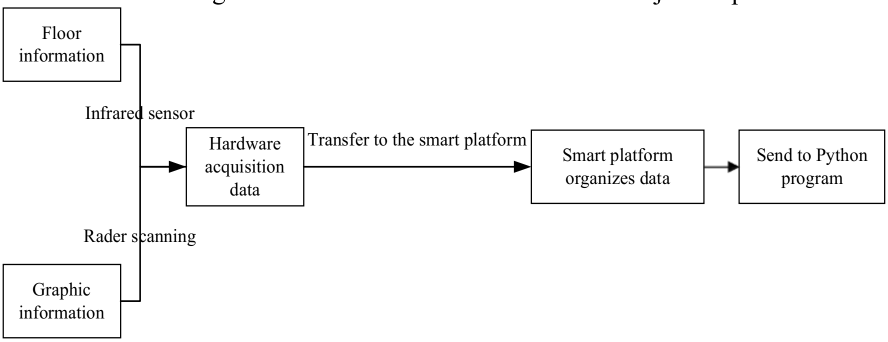

Fig. 4. Coordinate joint presentation flowchart.

5.2 Experimental design of joint positioning in BIM model

In the actual building of the project, the internal hardware equipment of the helmet is used as the transmitter of the electromagnetic wave signal. The lidar scans the floor plane, so that the signal receiver receives the electromagnetic wave signal emitted by the helmet and obtains the actual coordinate position of the worker. After processing the coordinate position through the Python program, this paper uses the Revit API NewFamilyInstance to accurately model the worker model in real time. In the Python program, define list X, representing the worker X coordinates; then define list Y, representing the worker's Y coordinates; define list Z, representing the worker's floor. The relevant data of the corresponding number of floors is stored in the list Z. According to the information obtained by the on-site infrared scanning equipment, it is transmitted to the intelligent management platform, and the platform transmits the corresponding layer number to the Python program. Traverse the Z list in the Python program to determine the floor number, and switch to the corresponding floor plan of the building in the Revit software to facilitate the subsequent implementation of corresponding modeling in Revit API.[11] Call the Python program corresponding to the Autodesk library, Revit. UI, Revit. DB, create a worker model, and unconditionally traverse the X list and the Y list. The number of traversal varies with the number of coordinates returned by the data, and the real-time path of the worker can be output in the Revit software. During the experiment, the sensor data received on the spot will involve the confusion of plane coordinates and height positions due to different receiving times, thus making the received information messy and the amount of data large. The intelligent management platform classifies the data in plane and height, and then extracts valid data from it. When the worker passes through the plane floor, the floor infrared sensor receives the worker's signal and transmits the signal to the Python program, and Figure 5 shows the workflow of height positioning.

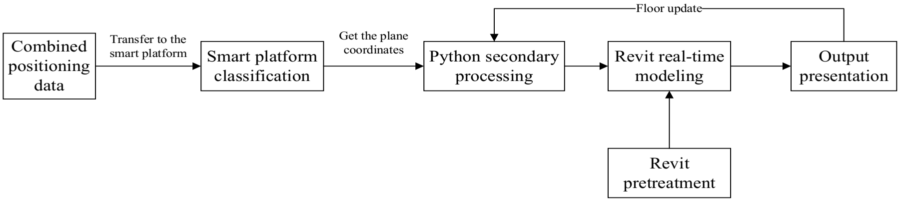

Fig. 5. Work flow chart of height positioning.

In the Revit software, preprocess the building model, use the section to switch the model view of a single floor, open the project base point in the Revit software, and move the project base point to the coordinates of the site receiving point in advance, so that the two match and prepare to receive the processing data in python. Assuming that the actual coordinates of the signal receiver are (0, 0), also known as the base point,[12] the position of the building base point is moved to the position of the signal receiver in Revit software at the same time to coincide with it. Set the coordinate accuracy of the signal transmitter so that it is the same as that of the Revit software. The experiment is determined according to the average cadence and movement speed of the person. The worker sends a signal every 0.5m of movement to observe the delay time it is updated in the Revit software. According to the experimental results, the delay time is about 0.5s.

6 Intelligent safety helmet danger warning experiment

6.1 Early warning and judgment methods for dangerous areas

Use the RevitPythonShell plug-in to obtain the API of Revit software, use Python program to link with the API of Revit software, so that Python and Revit software are isolated modeling data, and can modify the parameters of the model in Revit software through Python. The corresponding floor elevation value and worker coordinate location value are automatically entered in the Python program to realize the automatic modeling of Revit software in Python. Through the construction site map built in advance, the danger area of the BIM model is divided in advance, and the core coordinates of the danger area are defined at the same time The transmitted coordinate value is compared with the central coordinate of the danger area, and if the coordinate value is lower than the set value from the central coordinate of the danger area, the Python program starts the alarm program. If the worker is far away from the danger, the program prompts him to be outside the danger area, and the record is backed up in the background.

6.2 Early warning experimental design for hazardous areas

This paper takes an office building project in Zhabei District, Shanghai as an example. The project is a single commercial office complex with a total of 16 floors. One of the characteristics of this kind of building is the lighting roof area of the atrium. In the actual construction process of the project, it is a hollow area, which is more dangerous. It is prone to fall accidents during the construction of the project, and the elevator shaft runs through the 16th floor. During the construction process, the internal light of the building is dim, and it is easy to fall into the elevator shaft. In order to reduce the occurrence of such incidents during the construction process, coordinate data is transmitted in time according to the movement of on-site construction personnel, and the danger is determined by the Python program. When the Python program defines that the worker's distance is less than the defined dangerous area, the program issues an early warning of entering the dangerous area. Through the helmet, a dangerous area warning is issued to the user first. At the same time, the data is transmitted to the intelligent management platform and the corresponding Revit API modeling is carried out. The intelligent management platform records the alarm data and makes a collaborative warning to the relevant personnel on the site, and Figure 6 shows the hazardous area display of the project.

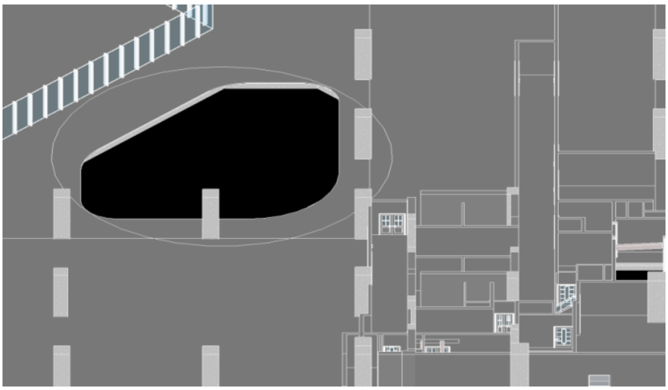

Fig. 6. Hazardous Area Map of the Project.

The coordinate system is established at the base point of the project (0,0). The coordinates of the center of the dangerous area of the project are (33000,24500), and the reserved value of the radius R of the dangerous area R of the project is 9500 < R < 9800, R is the artificially set non-hazardous zone buffer distance, that is, the worker is close to the dangerous area and automatically triggers the alarm. The area coordinates of the project are (26000,34000), (28000,36000), (34000,26000). After procedural determination, the coordinates (26000,34000) and coordinates (28000,36000) are not within the dangerous area, and the alarm program is not started. Coordinates (34000,26000) in the dangerous area, the alarm program is activated.

When the worker enters the dangerous area, the helmet and the platform issue a joint safety alarm. The alarm needs to be confirmed by the background of the intelligent management platform for a second time to confirm that the worker is carrying out a reasonable range of activities due to work needs to cancel the alarm. The intelligent management platform records the operation in real time. On the basis of ensuring construction quality and efficiency, we can promote and strengthen the quality, safety and civilized construction and management of the construction site of the project, and improve the production efficiency, management efficiency and decision-making ability of the construction site of the construction project [13].

6.3 Hazard warning and intelligent management platform design

The intelligent management platform continuously monitors the workers entering the dangerous area and displays the workers' travel path in real time. For workers in the safe area, the location needs to be displayed through human operation, and the path is displayed in green. If the worker is going to be in danger, the helmet issues an alarm and reminds the worker to stay away from the dangerous area. At the same time, the platform issues an alarm and automatically displays the worker's movement path. The path is dark, representing potentially dangerous workers. The path reminds managers to check the real-time location of workers. Managers can remind workers to stay away from the danger area through broadcasting, helmet communication, etc., or remind the managers in the area. If there is a danger, the platform path is dark and reported to the management at the next level. Figure 7 shows the color differentiation diagram of the intelligent management platform in different positions of workers.

Fig. 7. Regional color differentiation chart.

Considering the movement of workers who are not in the dangerous area, the platform will re-check and locate the height and plane coordinates of the workers according to the worker's movement trajectory data to ensure that the workers are in a safe area. The platform continuously refreshes the track data of workers to ensure the timeliness of the track data. Click the real-time motion scene in the menu bar of the smart management platform to watch the simulated travel route of the workers at the construction site refreshed in real time. Figure 8 shows the real-time roadmap of intelligent management platform staff.

Fig. 8. Real-time roadmap of intelligent management platform workers.

The platform will record the alarm information and alarm times in each area of the construction site. If the number of alarms in an area exceeds 50% of the whole area for a period of time, managers need to check the area, arrange relevant personnel to conduct safety inspections in the area, and make a corresponding alarm investigation report.

The intelligent management platform has an information storage function. For the path of ordinary workers, the platform will store one month's information records. For workers who have appeared in nearby dangerous areas and entered dangerous areas, the platform will store the path information for three months. If workers commit crimes on the construction site during construction, the intelligent management platform will permanently retain the workers' trajectory information.

7 Conclusion

Starting from the mobility and diversity of workers on the construction site, multi-process, multi-level and three-dimensional cross-operation in large-scale projects, as well as safety management functions combined with actual safety management work, this paper has added a new design that matches the current stage of scientific and technological development in terms of original safety performance. The smart helmet is equipped with a positioning chip to complete the real-time positioning of workers. The combined positioning method of this paper is divided into three parts: site map, smart helmet, and smart management platform. The intelligent management platform comprehensively processes all kinds of data and archives the basic information of each worker, so as to achieve real-time positioning of each worker, and the location information of workers can be found at any time. With the continuous advancement or improvement of the project, the originally divided dangerous areas will be updated and changed accordingly on the site map, and the data of the smart platform will also be updated accordingly.

Acknowledgments

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