International Journal of
Georesources and Environment
IJGE 2018 **4**(**3**): 153-162
http://ijge.camdemia.ca, ijge@camdemia.ca
Available at http://ojs.library.dal.ca/ijge
Research and Development and Industry

A Framework of a 3D DCPCS Based on UWB Positioning in Underground Mining

Haoyu Wang[1,2], Enji Sun[1*], Feifei Wang[1,2], Shuangyue Liu[2]
[1] China Academy of Safety Science and Technology, Beijing, China, 100012
[2] University of Science and Technology Beijing, Beijing, China, 100083

Abstract: The real-time positioning and information feedback of the underground workers and equipment play a key role to achieve the safety digital mine because of the complex work scenario of non-coal mining in China, especially the injuries and collisions caused by the alternate operation between operators and vehicle equipment in underground mining. There are relevant requirements in the safety hazard called "six systems" which includes the personnel positioning, communication links, monitoring and controls, but the results are not prominent after investment and construction for its ambiguous definition of the scope of the standard and reasonable defects. This paper aims to study the application of Ultra-Wide Band (UWB) in underground personnel positioning, by comparing and analyzing traditional underground positioning technology. Combined with 3D scanning three-dimensional modeling technology, the UWB signal can also be used to construct 3D digital interactive underground map to enhance the accuracy of positioning information and the intuitiveness of monitoring perspective in control center. The framework of a 3D dynamic comprehensive prevention and control system (hereinafter referred to as 3D-DCPCS) based on UWB positioning in non-coal mining is proposed, depending on the supports of these technologies. Among them, UWB is a non-carrier communication technology. Its signal has strong anti-jamming performance and high transmission rate, which can improve the accuracy of real-time underground positioning. And the interactive 3D modeling technology is a new type of media, which can enhance the user's sense of reality through the transformation of pilot and perspective view. This framework of 3D-DCPCS is designed to have some specific modules, including user identity management module, underground three-dimensional map module, 3D interactive monitoring window module, underground risk assessment module, anti-collision module of personnel and vehicle, safety information statistical management module and other functional modules. This system can achieve the functions of different users' identity role management, underground safety risk identification and grade assessment, map of underground risk area, precise positioning and dynamic control of underground operators' vehicles, remote control and communication of underground equipment and personnel and 3D dynamic monitoring of underground operation scenarios. Meanwhile, these functions can be targeted to update through a period of security information statistical feedback. The system can be applied to comprehensive prevention and control monitoring of correlative complicated operating environment, by relating to the mentioned framework and specific situation of non-coal mine. It would be of practical values to improve the safety of underground personnel, standard safe operation of mechanical equipment and man-machine orderly cooperation in underground non-coal mine if it would be built and put into application.

Keywords: digital mine, 3D dynamic map, UWB positioning, comprehensive prevention and control system

1 Introduction / Background

China is a country of rich mineral resources (Zhang 2015). At present, there are 173 kinds of exploited minerals in China and China is the third most productive country in the world after the United States and Russia (Wang 2013). According to national statistics, with its huge mining industry, 94,753 non-coal mines have been discovered in China by the end of 2007 (Xie 2009). China has a large number of non-coal mines. However, they are widely distributed, which is a disadvantage to safety management, especially underground mining operations. In the event of an accident, the rescue difficulty and casualties are usually large. And even in standard operations, accidents involving personnel and vehicle equipment occur quite frequently due to the harsh underground environment, such as darkness and dampness, high dust concentration, high noise etc. Also, the problem of comprehensive control of underground personnel demand prompt solution. The "13th five-year" plan proposed new demands for the construction of high technology based on intelligent mines and the development of the supporting technology for unmanned working face (He et al 2015). In addition, according to the development route of the deep integration of information technology and manufacturing industry proposed in "made in China 2025" (Zhou 2015), a number of emerging technologies such as 3D digital media and the Internet of Things would be continuously applied to the mining industry, in order to

* Corresponding Author: Enji Sun, Email: enjisun@gmail.com, phone: +86 10 8491 6155

DOI: 10.15273/ijge.2018.03.025

improve the security capacity of underground production. In 2010, China issued a series of related documents and saw the construction of "six major systems" of non-coal mines launch. However, the following results could not meet the original expectation mainly due to the problems such as ambiguous scoping caused by a system with extensive covering range and the unrealistic standard regarding personnel positioning and communication. The ideal solution is to establish an informationized and digitalized multi-model mines based on mine multidisciplinary information including science and technology, information science and artificial intelligence. This also answers to the national " 13th Five-Year" plan as well as meet the future development trend of mining, (Liu 2011) The key to achieving this goal is to ensure the working staffs and devices is located accurately and achieving real-time feedback by introducing advanced technology and experience in other fields.

In related fields, Liang Bosen et al. propose that the trend of in the field of mine monitoring is accurate positioning, 3D visualization, multi-system integration, Internet of Things and multi-data mining, which provides a direction for the design of this article (Liang 2017). Xu Hualong, Yin Dafa and others put forward the mine 3D visualization monitoring system design ideas and related applications using 3D GIS technology and virtual simulation technology. The system can provide 3D underground real-time monitoring (Xu and Ying 2016), but there is a lack of corresponding solutions in the control of personnel and vehicle irregularity and the risk in different areas in the mine. Li Chunmin et al. constructed the 3D visualization framework model of "digital mine", through data manipulation, mapping and drawing (Li et al 2006), which is worthy of reference in 3D modeling. On the basis of this research, this paper focuses on the two core technologies of personnel positioning and 3D visualization. Firstly, we analyzed the current positioning technologies and designed the construction scheme of the positioning subsystem by choosing the UWB and the corresponding algorithm. After that, the 3D scene construction scheme was designed with the help of 3D modeling technology. With the support of two core technologies, the framework of 3D-DCPCS was proposed. This paper researched on the construction of the framework and analyzed specifically some key functions of it including 3D interactive monitoring window, security risk assessment and anti-collision module for personnel and vehicle.

2 Key Technology of System

2.1 Positioning technology

At present, GPRS is different from GPS, which the satellite is the receiver (Sun et al 2010a). GPRS accounts for a large market, and its clients use mobile phone to send signals to the communication base station. (Zhang 2014) Consequently, the positioning accuracy of GPRS depends heavily on both the intensity of the signal and the number of base stations. The challenges for positioning technology are even bigger because of the harsh conditions in the well. Nowadays the commonly used under-well positioning technologies are ultrasonic, Bluetooth, Wi-Fi, RFID, ZigBee and UWB, etc. The positioning methods can be roughly divided into range-based measurement and range-free measurement, and the related positioning algorithms are AOA algorithm, TOA algorithm, TDOA algorithm, RSSI algorithm and fingerprint location algorithm (Lazos and Poovendran 2006)

2.1.1 Choosing the proper positioning technology

(1) Wi-Fi positioning technology

Wi-Fi positioning technology is the most popular and a promising technology among under-well positioning technologies. The establishment of Wi-Fi position system is feasible and low-cost, but with unsecured accuracy. The users with the mobile intelligent terminal enters the underground operation area of the base station (router). On receiving the results of data processing from the clients, the server can then calculate the location. The more signals the smart terminals receive, the more accuracy the system will achieve. The demonstrative diagram of the Wi-Fi positioning system is presented in Figure 1.

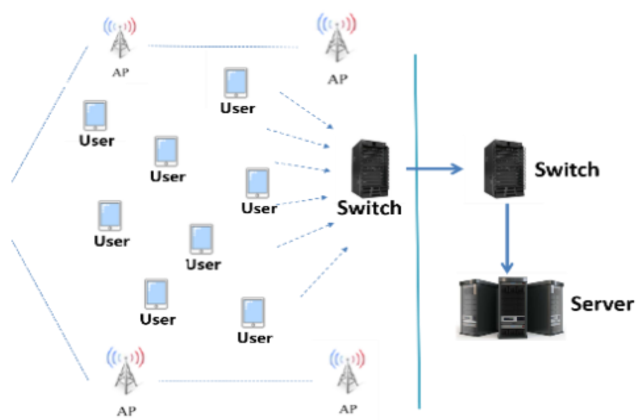

Figure 1 The diagram of Wi-Fi positioning system

(2) Radio frequency identification technology (RFID)

RFID is an high-speed recognitive, non-contact automatic wireless communication technology (Ahuja and Potti 2006) It uses radio frequency to recognize and distinguish the relative data of the target so it’s capable of fast reaction and strong resistance to interference. Typical RFID system consists of Antenna, Reader, Tag (also called radio frequency recognition card), middleware and software based on RFID technology (Zeng and Zhao 2010) When people or vehicles carrying an electronic tag enter the transmitting area, the tag will send a signal which contains the information to the reader. The reader will decode and transmit it to data management system and the location information can be calculated afterwards. FRID technology is convenient to set up, but the positioning accuracy is not promising. In practice, it is commonly used for the attendance check in actual underground work. The illustrative diagram of positioning system is shown in Figure 2.

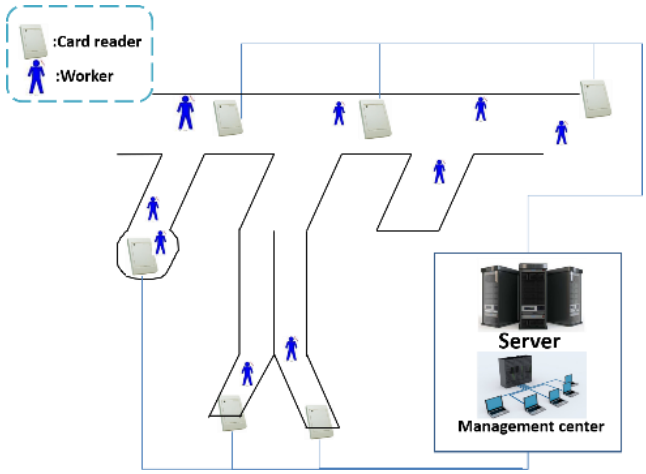

Figure 2 The diagram of FRID positioning system

(3) Zigbee communication technology

Zigbee technology is an emerging short-range wireless communication technology (Gu and Zhang 2005) It has the characteristics of low complexity and short bidirectional communication distance. It is a highly adaptive wireless network composed of many nodes. Its schematic diagram is introduced in Figure 3. As we can see in the picture, in the entire wireless network, by using frequency-hopping spread spectrum (FHSS), communication can still hold even when one node fails within the network. Zigbee communication technology is also used as location technology because of the wireless communication function. The function principle of the system is similar to that of the RFID positioning system. The biggest advantage of this technology lies in the low establishment cost, high security, despite the drawback of low positioning accuracy.

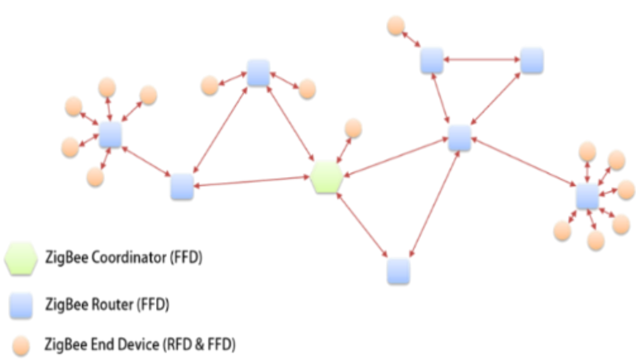

Figure 3 The diagram of Zigbee positioning system

(4) UWB positioning technology

UWB technology is also known as ultra-wideband wireless technology with bandwidth over 1GHz. The signal has strong anti-interference performance and high transmission rate (Shen et al 2005) UWB positioning system is mainly composed of software platform, wireless sensor and the active positioning labels, the working principle of which is shown in Figure 4. When personnel or vehicles enter the operation area, the active positioning tag that they wear will Send UWB pulse signal. The pulse signal will be received by the base station. The location of the target is calculated by positioning algorithm and transmitted to server terminal via Ethernet. UWB positioning technology is one of the most advanced positioning technologies with advantages of simple structure, low power consumption and high transmission efficiency etc.

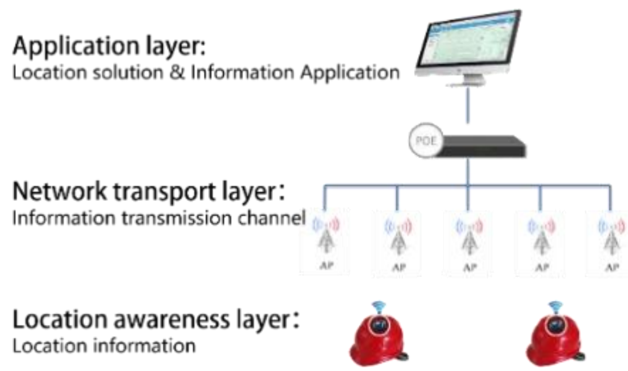

Figure 4 The diagram of Zigbee positioning system

(5) Bluetooth positioning technology

Bluetooth is a short-distance wireless communication technology mainly used to enable the communication among wireless devices. It was first developed by Ericsson in 1994 (Chen and Zheng 2003) The working principle of Bluetooth positioning technology based on the received signal intensity. Bluetooth chip is small so that it has low power consumption, But the positioning range can also be very limited.

According to the above mentioned positioning technologies , in terms of working condition—non-colliery underground well and by comparing the technologies in Table 1,we could conclude that UWB positioning technology is more suitable for underground well site because it has fast transmitting rate, simple structure, superior safety, low power consumption, better signal penetrability, stronger anti-interference ability and better positioning accuracy, all of which can contribute largely to a successful underground well positioning.

Table 1 Comparison table of positioning technology

	Frequency	Precision	Speed
Wi-Fi	2.4GHz	≤10m	54Mpbs
FRID	LF:125KHz; HF:13.54MHz	10~30m 3~10m	12Mpbs
Zigbee	868~915MHz 2.4GHz	10~75m	10～250Kbps
UWB	3.1~10.6GHz	5~30cm	40～600Mbps
Bluetooth	2.4GHz	15m	1Mbps

2.1.2 Positioning algorithm

Currently, the algorithms related to UWB localization technology fall into two broad categories: range-free localization algorithm and range-based algorithm. And fingerprint localization algorithm is the most typical range-free measurement algorithm. The localization procedure is illustrated in Figure 5. The radio waves emitted by wireless AP node leave important multipath signal, which is named the "fingerprint of position", when they undergo refraction, diffraction, etc. while passing through its surroundings. (Rong and Yang 2010) The algorithm of this method is to first extract the characteristic parameters of radio signals; then compare them with the modules in the database via certain coupling algorithm; finally locate the most similar group or several groups of data and lock the position. However, fingerprint algorithm is prone to fail the instantaneity and accuracy of the positioning, so range-based measurement would be a better candidate.

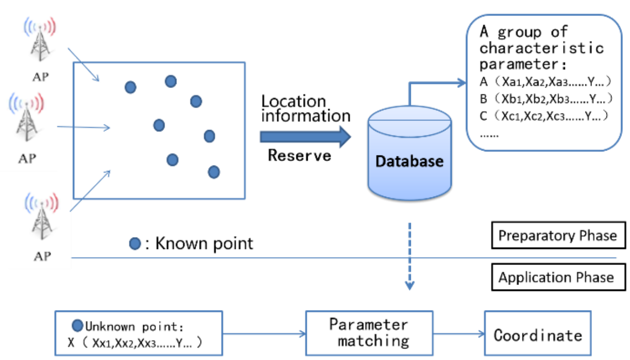

Figure 5 The localization procedure of fingerprint localization

Commonly used range-based localization algorithm are AOA algorithms, TOA, TDOA algorithm and RSSI algorithm. AOA measurement is based on the arrival angle of the signal while TOA and TDOA use the signal arrival time to calculate the distance. RSSI uses the extent of the signal decay to calculate the location. According to the characteristics of these algorithms listed in Table 2, it could be concluded that TDOA triangulation method is more suitable in the working condition of this paper.

Table 2 Comparison table of positioning algorithm

Positioning algorithm	AOA	DOA	TDOA	RSSI
advantage	Simple in structure, higher precision	Higher precision	High precision	Low cost, easily realized
defect	Susceptible, higher equipment	higher equipment	More equip-ment	Lower precisi-on

Based on TDOA algorithm, it needs at least three coordinates of AP node to locate the coordinate of the unknown point. At certain moment, the distances between positioning point and different AP nodes are different. As the transmitting velocity of the signal is known, the distance difference can be calculated using formula $d = v(T_1 - T_2)$. Analogously, the distance difference d can be drawn by multiple hyperbolas, as shown in Figure 6.

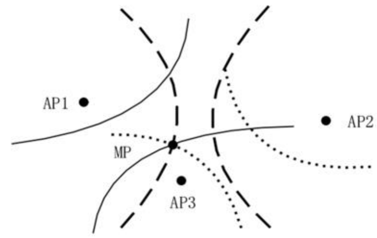

Figure 6 The positioning algorithm of TDOA

Combining the geometric model in Figures 2 and 3 with the lag time of different target-and-AP node-pairs calculated in the TDOA, it could be inferred that the positioning terminal lies in the hyperbola which uses the two AP-node coordinates as its focuses. Two hyperbola formulas could be conducted by three known AP nodes and the intersections of these hyperbolas are the position of the terminal. The coordinates of the terminals could in turn be obtained by solving the hyperbola formulas. However, in practical applications, there are many occasions when there is no overlap between the two intersections of the hyperbola, so the method of triangle centroid is needed to determine the anchor coordinates.

2.2 3D visualization technology

With the development of computer technology, two-dimensions figures cannot satisfy the requirements of users. Instead, three-dimensions technology have been applied to video production, which allow users to have a more vivid experience while enhancing level of lifelikeness of real people and objects.

2.2.1 3D scanning

3D scanning is an advance technology integrating light, machine, electricity and computer technology. It can obtain the space coordinates of the object surface by scanning object space shape, structure and color. 3D scanning can convert the stereoscopic information of underground tunnels, working environment and related equipment into digital point cloud information that can be processed by a computer, which can achieve the digitization of the underground scene. The 3D scanning technology can realize the non-contact measurement in the mine and has the advantages of fast measurement and high precision. The measurement results can be directly connected with various software interfaces.

Non-contact 3D scanners conclude raster 3d scanners (also known as photo-type 3d tracers) and laser scanners.

Photo-type 3D scanner adopts a composite 3D non-contact measurement technology, which combines structure light technology, phase measurement technology and computer vision technology. The scanner can adjust the scanning range according to the condition of the underground. It is suitable for large equipment and the overall scanning of the specific area, which can guarantee the scanning integrity and efficiency. The photo-type scanning principle is shown in Figure 7. The measuring instrument uses similar principle of the camera to obtain the

3D information of the object. In non-coal mines, underground photo-type 3D scanner can adjust the position and angle according to the site, carrying out omni-directional measurement; or implement real-time automatic merging, carrying out the partition measurement.

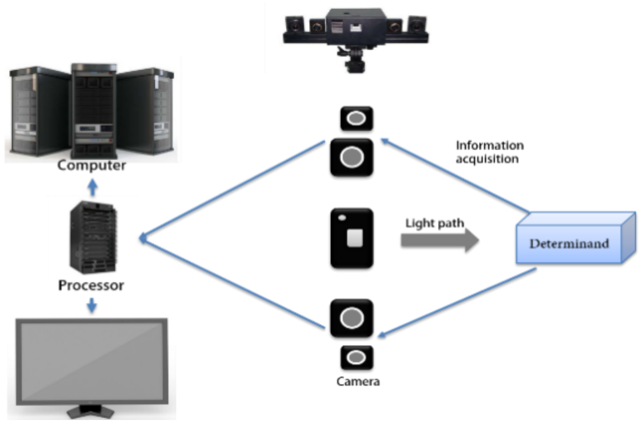

Figure 7 The sketch map of photo-type 3D scanner

Line laser handheld 3D scanner is suitable for scanning small workpiece. Before use, calibration is needed. When working, the laser line irradiates the object, which allows two cameras capture the 3D scan data of that instant. Due to the curvature of the surface of the object, the light is reflected and refracted before these information is converted to 3D images by third-party software. The hand-held 3D scanner is designed on the basis of the photo-type 3D scanner. Scanning the point cloud image on the surface of the object, these points can be used to interpolate the surface shape of the object. The accuracy of the model is in line with the density of the point cloud, which contributes to the quality of 3D reconstruction.

2.2.2 3D scene construction

(1) Technical analysis of 3-Dmodling

There are several frequently-used foreign 3D modeling software such as 3ds Max, Maya, SketchUp, etc. And the frequently-used 3D model scene displays software, are ArcGlobe, SkyLine, GeoGlobe, etc. As for domestic software, VRMap created by Beijing Lingtu Software Technology Co., Ltd and IMAGIS made by Supresoft Inc are leading the pack.

We can see the modeling software's function and advantages from the Table 3. In all, 3ds Max is superior to other software in terms of operational convenience and possibilities and will be used as main 3D modeling software in this system.

(2) Creating 3d scene of underground well

The actual effect of the underground monitoring display window depends largely on the previous 3D scene construction. The core work of the underground scene modeling is to analyze and process the point cloud information, mine drawings and topographic information of the 3D scanning. Through the 3D modeling software, a model is established for the tunnel working face, equipment, vehicles and workers in the mine. Finally, 3D restores the real scene into, 3D scene files for later use in related process steps. The concrete underground 3d scene construction is divided into three parts, including data collection, data processing and model integration. The concrete building process will be introduced in the following page.

Table 3 Comparison table of modeling software

Name	Advantage	Defect
3ds Max	Complete function,	Complex texture
Sketch Up	Rapid modeling	Insufficient information
SkyLine	Lots of 3D data scenarios.	Differential monomer modeling
Maya	All-round CG function	Focus on film

3 Studies of System Framework

3.1 System construction

Combining the actual situation of non-coal mines, this paper focus on constructing non-coal mine comprehensive monitoring and controlling system applying above mentioned two technologies. The establishment of the system is the core issue to be solved and discussed in this paper. Upon completion, the system should be equipped with functions including identity authority management of different users, underground safety risk identification and grade assessment, downhole risk area map, precise positioning and dynamic control of downhole workers' vehicles, remote control and communication of downhole personnel equipment and 3D dynamic monitoring of downhole operation scenarios. In the process of establishing the system, many issues including technology, personnel and procedures should be taken into consideration. The following section is a research on the establishment of overall system and specific steps.

3.1.1 The global perspective of system

The establishment of system in the overall perspective can be divided into four steps: 3D map construction of downhole, downhole risk identification and assessment, downhole positioning subsystem construction, system operation and monitoring, as shown in Figure 8. Every step operates with the support of Software programming, model building, background maintenance and other technologies. 3D map building Downhole is the foundation of the system framework, which provides a platform for the establishment of positioning and monitoring subsystems and system-related services. Downhole risk identification and assessment is a core content of underground safety work, which provides corresponding basis for the routine operation and maintenance of system. The construction of positioning system aims to solve the locating problem of downhole personnel and equipment, which incorporates positioning information into the 3D underground map, realizing the dynamic map (i.e. the three-dimensional monitoring of downhole operation). Finally, the system enters the actual operation and monitoring phase, in which the system will be improved according to the actual situation.

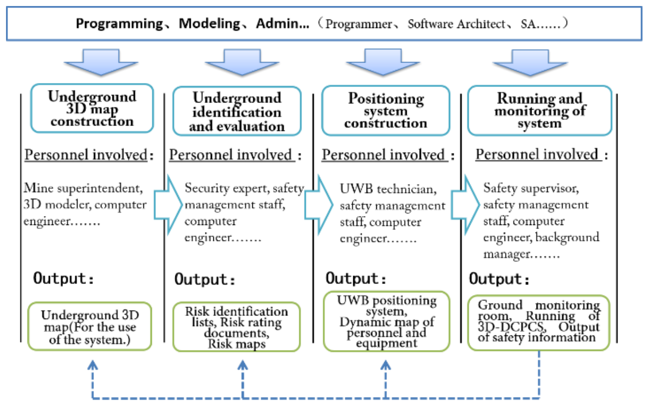

Figure 8 Overall system construction

3.1.2 The step of construction

The following section researches on the construction of 3D underground map, underground mine risk identification and assessment, underground positioning subsystem construction and system operation and monitoring.

(1) 3D map construction of downhole

As shown in Figure 9, we start with the collection of mining data, which includes the specific types of mines, types of minerals, geological conditions of mines, depth of mines and the progress of mining. After acquiring the basic information of the mine, the site survey of working environment is carried out. The underground personnel vehicles and roadways are scanned by 3D scanning technology. Then, with the drawings and photos and other information, all regions of mine and personnel vehicles are modeled with 3D modeling. The three-dimensional models of different regions are spliced to form a downhole three-dimensional model of all dimensions, i.e. 3D underground map.

Three-dimensional scene modeling of downhole is the key to the system construction, influencing the post-performance of 3D monitoring of system and the fidelity of picture presented. For underground non-coal mines, the flow chart of specific three-dimensional modeling construction shown in Figure 10 includes three major steps: The collected data includes point cloud data obtained by 3D scanning, mine drawings and other information. Data collection should be as detailed as possible to restore the scene in a truer manner in the modeling process. Data processing is a procedure to process the data by the existing corresponding data processing and modeling software, in order to formulate the 3D model of the local scene. The final model integrates the existing three-dimensional scene model to form a whole three-dimensional model and a model for each working face. And after adding the underground equipment, vehicles and personnel models, it can obtain the 3D scene display of the real underground scene.

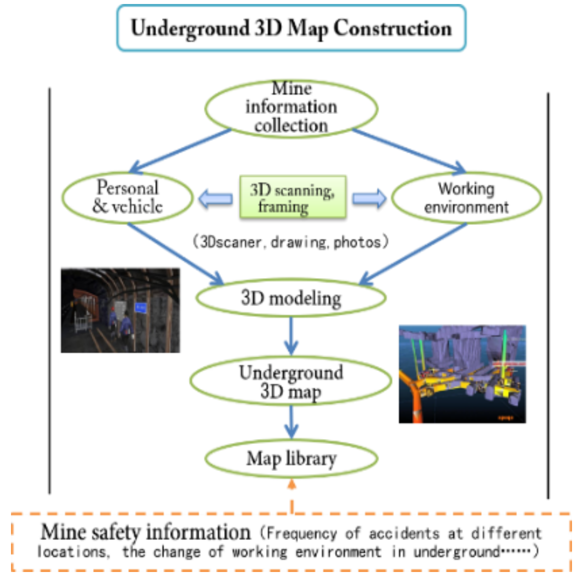

Figure 9 Underground 3d map construction

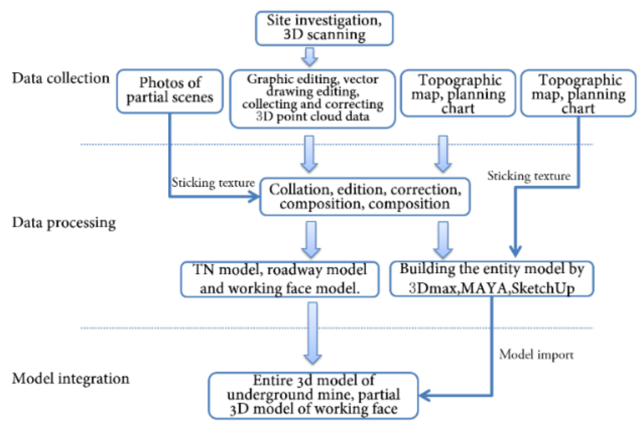

Figure 10 Underground 3D modeling

We transform the files of 3D scene model of downhole in a variety of formats, in order to facilitate the function modules of the system. By writing a system program, we build a detailed underground map library. The map library includes the whole underground, each face, as well as each key area of the three-dimensional model. The mine safety information is generated by the fourth part of the system's safety information management module. Through the feedback of safety information, the three-dimensional model in the map library is evaluated, and the three-dimensional model that does not match the real scene is modified or re-modeled.

(2) Underground risk identification and assessment

Downhole risk identification and assessment of business and business safety work is directly related to the risk identification. Risk identification and risk rating information play the role of guidance for the design and upgrade of function of system. The flow diagrams of downhole risk identification and assessment are shown in

Figure 11. Firstly, according to the basic information of the mine, combined with the relevant industry standards of non-coal mines, we developed the original version of the risk identification documents, and initially identified the non-coal mine underground danger source. Afterwards, having a knowledge of the enterprise and the status quo of production safety, we carry out the underground investigation to statistically analyse the past accidents of the enterprises. And by doing so, we improved the quality of the enterprise's risk identification documents. And then through expert assessment, model calculation and other means of hazard classification, we finished underground risk classification files, finally forming downhole risk map. Underground risk map is a presentation of risk rating, which combines the grading results with the downhole map and shows different colors on the map according to the number and level of the dangerous sources. And it achieves a more intuitive observation of the dangerous situation in each area. The mine safety information will be fed back to the three outputs, namely, downhole risk identification documents, downhole risk classification documents and downhole risk maps for updating and modification.

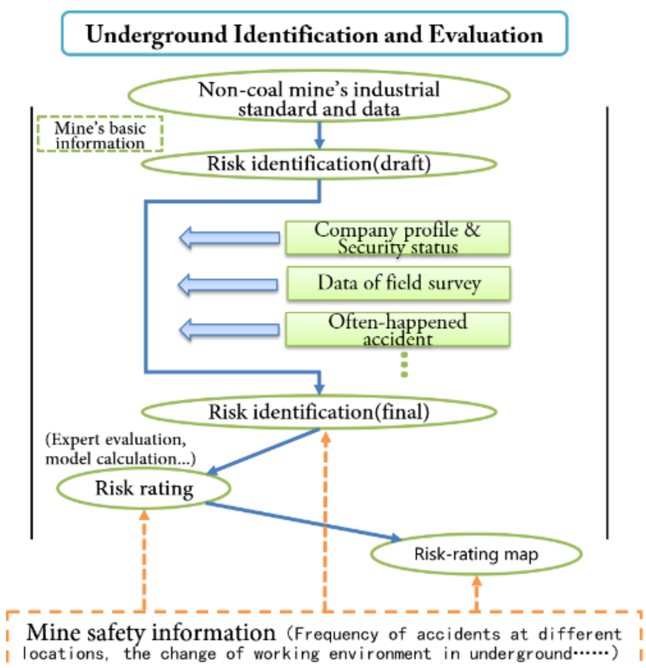

Figure 11 Underground risk identification and assessment

(3) Construction of underground position system

The sub-system of underground positioning can be illustrated in Figure 12. Before the establishment, detailed exploration of the mine should be carried out for comprehensive situation of the mine, including the location of the base station and the wires. The placement of base station should be based on the regional risk level because the data precision can be improved by increased base station number. As a result, the region with higher risk level should be equipped with more base stations to ensure the practical efficiency. When the establishment of base stations and wires is finished, the server can be added and related software can be programmed. According to the different identification of the users, different labels can be utilized in the positioning system. And the related functions in the sub-system are started up. Ultimately, the sub-system, underground 3D map and the models of people and equipment are combined together to realize the 3D demonstration of positioning information of underground people and devices, which is the underground 3D dynamic map. According the practical operation results, the location of the base stations and wires can be modified based on the feedback of the prior design.

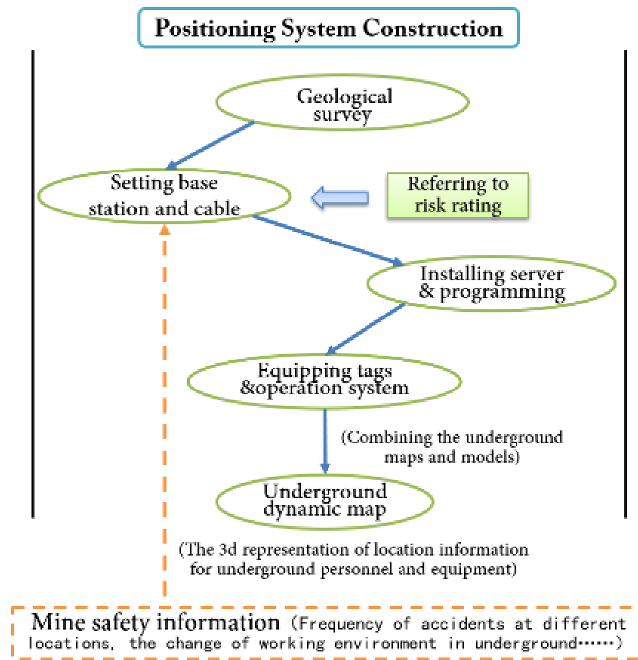

Figure 12 Underground risk identification and assessment

(4) Running and monitoring the system

The operation and monitoring of the system can be illustrated in Figure 13. According to the aforementioned results, the following steps should be carried out for operation of the system: 1) establishment of the surface monitoring room related devices; 2) programming the system and software of comprehensive monitoring and controlling; 3) administration of the original setting in the system background, including systematic prior settings, identification and authority of the users and division of the underground zone. When the system is operated, there are six main functional modules in the process: administration of the identification and authority of the users, 3D interactive monitoring, database of the 3D underground map, underground risk level ranking and prevention of underground crashing and supervision of the security information. The feedback from module of supervision of the security information can be provided to the other modules.

3.2 Achieve the system function with various modules

The whole system is mainly composed of user identity and permission management module, three-dimensional (3D) interactive monitoring window module, underground 3D map library module, underground risk rating module, underground collision avoidance module, security information management module. After the construction of the system, these modules will be triggered by different ways to achieve the function of the entire comprehensive monitoring and control system. Analysis and interpretation of these modules and its functions are as follows.

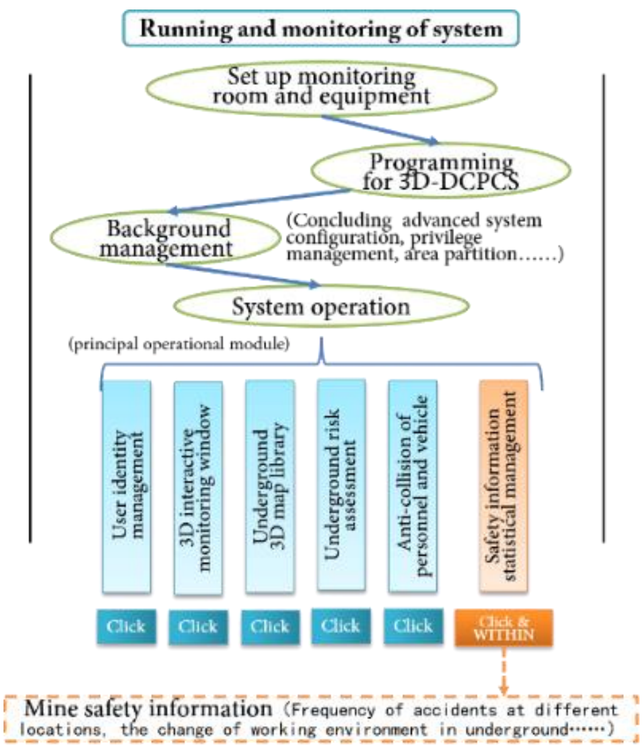

Figure 13 Running and monitoring the system

3.2.1 User identity and permission management module

As an auxiliary module, user identity and permission management module mainly contribute to the management of various users including addition and deletion of users, setting and modification of user's data, usage record of the system and so on (Figure 14). With the help of this module, employees would be managed more efficiently by personnel classification management. In addition, more detailed and concrete information of miner and their job information can be obtained.

3.2.2 3D interactive monitoring window module

The 3D interactive monitoring window is the core function module of the system (Figure 15). Generally, monitoring is the normal interface of the module. In the three-dimensional scene, the visual image reflects the position information of the underground equipment, vehicles and miners. The interactive monitoring means that the monitoring personnel can achieve changes in perspective and zoom into and out of the images, as well as provide real and efficient management information in monitoring personnel by viewing the relevant information of specific person and equipment.

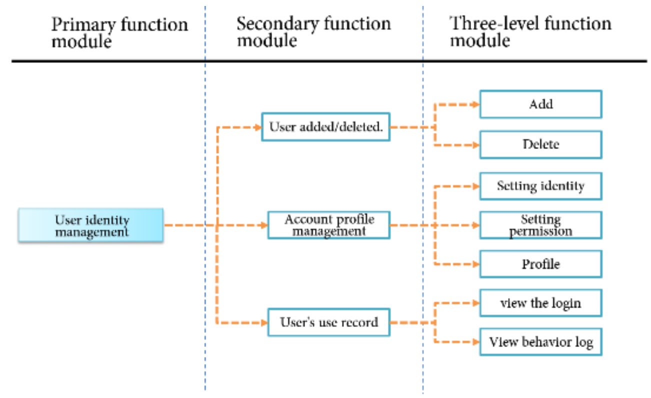

Figure 14 The function classification of user management module

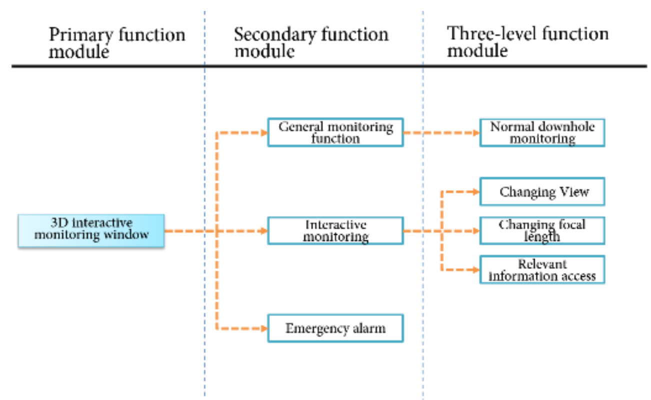

Figure 15 The function classification of the 3D interactive monitoring window

3.2.3 Underground 3D map library module

Underground 3D map library (Figure 16) is the basic module of the system, not only can it provide users with a way to view underground operating environment and to achieve the inspection and modification of 3D model which covers the whole underground area, each working face and key area, but can also to provide job scene model for those core modules, such as interactive monitoring window and risk map.

3.2.4 Underground risk rating module

Underground risk rating module is the innovation module of mine security control work, which provides users with relevant data files about underground risk identification and classification, as well as the risk map and risk map, the combination of data and 3D underground scene model. As shown as in Figure 17, the users will have more intuitive understanding of underground risk distribution and risk level so as to carry out the underground danger zone partition.

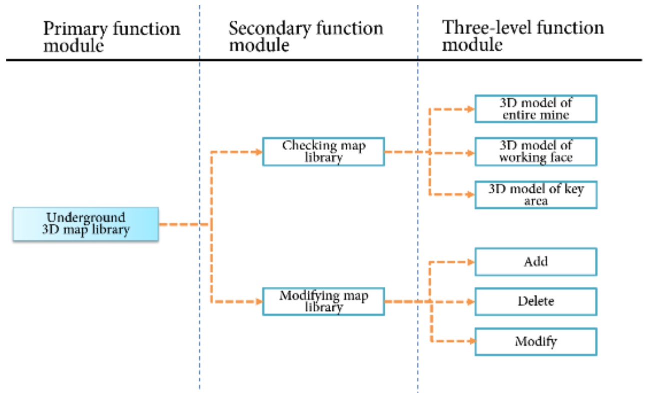

Figure 16 The function classification of underground 3D map library module

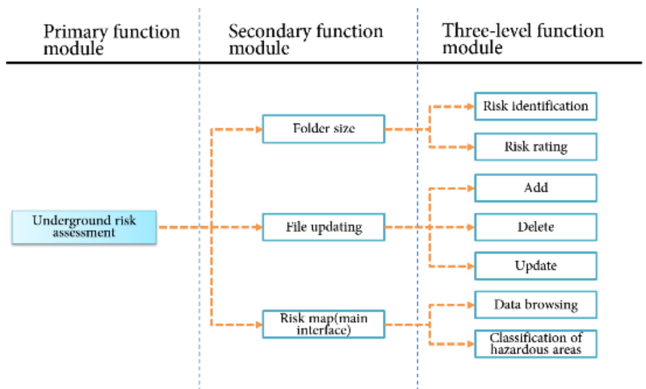

Figure 17 The function classification of underground risk rating module

3.2.5 Underground collision avoidance module

Underground collision avoidance (Figure 18) is a real-time module, which is the main function part under the normal operation of the system. The system will alert related personnel when they are in improper alternate operation or enter the hazardous area. Based on assisted driving system and route guidance functions, it helps users manage and control underground miners and vehicles to prevent collisions and accidental entry in dangerous areas (Sun et al 2010b).

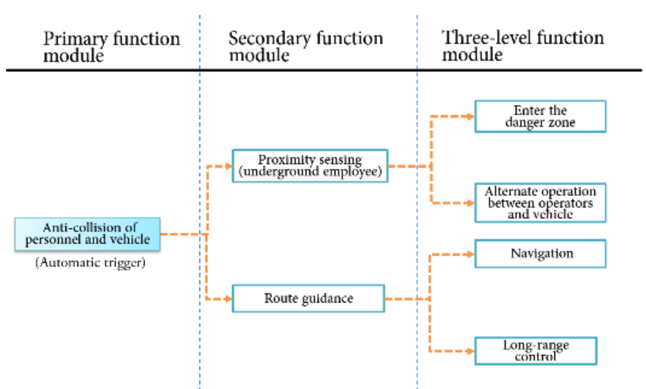

Figure 18 The function classification of underground collision avoidance module

3.2.6 Security information management module

Security information management consists of data processing and storage feedback functions, which records various types of real-time information generated during the operation of the system. As shown as in Figure 19, after mine security information being collected by means of analysing these information, the corresponding feedback will be shared to other related functional modules to upgrade and improve the system. In addition, as a browsing module, it can also be used as a tool for inspector to check whether the underground workers complete the work according to the criteria.

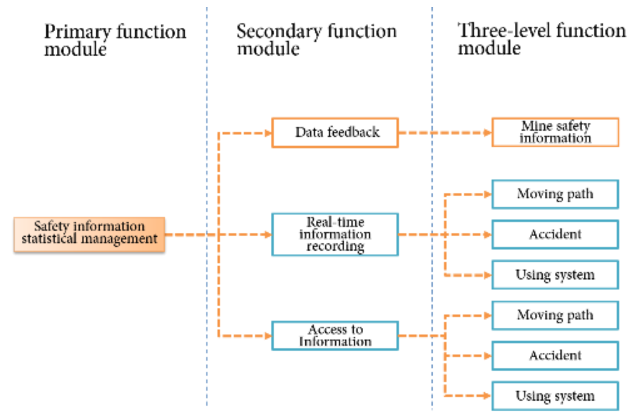

Figure 19 The function classification of security information management module

4 Conclusion

In this paper, two key technologies applied in non-coal mine shaft are discussed. And the question of how to construct the 3D dynamic control framework based on UWB positioning and the functional business modules are analyzed. Through the gradual implementation of the system construction, combined with the specific situation of the mines, the construction of the system could be finally completed and put into practice. This system can not only be applied to the underground operation of non-coal mines, but also provide comprehensive control and monitoring services for other complex operating environments. By running six business function modules, the system can intuitively understand the underground operation conditions, which improves manageability, and it can also promptly alarm the miners and equipment about the possible dangers and, prevent the occurrence of an accident. Therefore, it has practical application value on improving non-coal miners' safety, as well as ensuring the standard operation of mechanical equipment and the orderly human-machine coordination.

Acknowledgement

This research project is made possible through the financial support from National Key R&D Program of China (2017YFC0805100, 2016YFC0801305).

References

Ahuja, S. and P. Potti, 2006. An introduction to RFID technology. (radio frequency identification) (Report). IEEE Pervasive Computing, **5**(**1**): 25 - 33.

Chen, J. and Z. Zheng, 2003. Introduction of ericsson bluetooth chip ROK101007. Electronic Design Engineering, (**6**): 36 - 39.

Gu, R.H. and H.K. Zhang, 2005. Wireless network technology and its application based on ZigBee. Application of Electronic Technique, **31**(**6**): 1 - 3. (in Chinese)

Lazos, L. and R. Poovendran, 2006. HiRLoc: high-resolution robust localization for wireless sensor networks. IEEE Journal on Selected Areas in Communications, **24**(**2**): 233 - 246.

Li, C.M., Z.X. Li and Y.H. Wang, 2006. Research on 3d visualization of “digital mine”. Journal of System Simulation, **18**(**s2**): 515 - 518. (in Chinese)

Liu, L., 2011. New trends in modern mines: Automation and intelligence. Mining Equipment, **(7)**: 34 - 37. (in Chinese)

Liang, B.S., 2017. Current situation and development trend of coal mine safety monitoring and monitoring. Inner Mongolia Coal Economy, (**12**): 71 - 72. (in Chinese)

Rong, X.F. and N. Yang, 2010. Localization error analysis and simulation of RSSI position fingerprint. Journal of Xi'an Technological University, **30**(**6**): 574 - 578. (in Chinese)

Shen, X., W. Zhuang, H. Jiang and J. Cai, 2005. Medium access control in ultra-wideband wireless networks. IEEE Transactions on Vehicular Technology, **54**(**5**): 1663 - 1677.

Sun, E.J., A. Nieto and Z.X. Li, 2010a. GPS and Google Earth based 3D assisted driving system for trucks in surface mines. Mining Science and Technology, **20**(**01**): 138 - 142.

Sun, E.J., A. Nieto, Z.X. Li, and V. Kecojevic, 2010b. An integrated information technology assisted driving system to improve mine trucks-related safety. Safety Science, **48**(**10**): 1490 - 1497.

Wang, G.F., 2013. Safe and efficient mining technology and equipment of kilometer deep well in Innovative coal mine. Technology for mining the deep well of coal mines in China. (in Chinese)

Xie, K.N., 2009. Analysis on safety production management of non-coal mine mountain enterprises. Work Safety & Supervision, (**2**): 26 - 27. (in Chinese)

Xu, H.L. and D.F. Ying, 2016. Design and realization of 3d visualization monitoring system in mine. Coal Mine Safety, **47**(**7**): 136 - 139. (in Chinese)

Zeng, W.B. and J. Zhao, 2010. A design of electronic tag antenna based on RIFD technology mine safety tracking system. Mine Safety, **41**(**9**): 74 - 77. (in Chinese)

Zhang, J.W., 2014. Comparison and summary of the characteristics of BEIDOU positioning system and GPS system. Electronic Technology and Software Engineering, **(7)**: 65 - 66. (in Chinese)

Zhang, H.T., 2015. Situation of mineral resources in China. Zhejiang geological society 2015 academic annual meeting. (in Chinese)

Zhou, J., 2015. Intelligent manufacturing--Main direction of “Made in China 2025”. China Mechanical Engineering， **17**(**001**): 2273 - 2284． (in Chinese)