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Application of Unmanned Aerial Vehicle 3D Model to Comprehensive Supervision of Mining and Virtual Simulation Training and Teaching

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Our subject in this research is an open pit mine under the jurisdiction of a district, and we have built a comprehensive supervision system for mining based on the remote sensing technology provided by an unmanned aerial vehicle (UAV) and the global navigation satellite system (GNSS). We used Phantom 4 as the data acquisition device in the open-pit mine to establish a real-scene 3D model of the mine. A 3D geographical fence was constructed by adding the spatial data of mineral rights. On the digital pedestal of a real-scene 3D model, one can achieve quantitative supervision through multi-temporal comparisons. The use of GNSS sensors enabled us to obtain positioning information and trajectory of the mine cars to achieve an automatic warning system. In addition, we simultaneously built a virtual teaching platform to simulate the entire process of mine supervision. Our research results show that the effective combination of UAV remote sensing technology and GNSS technology improves the integration of multi-source monitoring data and brings about significant breakthroughs in the field of the intelligent supervision of mines. The construction of a virtual simulation platform has been used to educate a large number of remote sensing technology application personnel and has value as a tool for teaching.

1. Introduction

Mineral resources are important material prerequisites for human production work and play an irreplaceable role in promoting the economic development of a country.[(1)] As an industrialized

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economy moves into a high growth phase, however, many enterprises mining indiscriminately have caused serious ecological damage.(2) Open-pit mining needs regular and all-round supervision to ensure the sustainable development and utilization of mineral resources. Most mines are scattered, remote, and exist in areas with complex terrains. The manual supervision method has the disadvantages of high labor intensity, long supervision periods, and high safety risks, and accuracy cannot be guaranteed.(3) People have stricter requirements for measurement accuracy, range, and definition of the positioning system. In contrast to traditional measurement techniques, the global navigation satellite system (GNSS) technology offers high positioning accuracy, easy operation, and the ability to operate in any weather. Its application has gradually expanded to transportation, environmental protection, geological disaster monitoring, and other fields.(4–7) In the field of mine supervision, through various technologies of perception, information transmission, and processing, a "sensor mine" has realized the visualization, digitization, and intellectualization of a real mine and its related phenomena. Some experts use smart sensing technology to monitor mine deformation, safety, production conditions, the concentration of dangerous gases, and other aspects.(8–11) However, most studies rely on a single piece of data, whereas mine monitoring should be applied to all aspects of the operation. It is truly insufficient to rely on isolated of pieces data for monitoring.

With the development of technology, unmanned aerial vehicles (UAVs) may be combined with sensors to identify targets and reveal their changing patterns by collecting electromagnetic wave information. UAV remote sensing technology has the advantages of flexible data collection, timeliness, high resolution, and the ability to provide 4D services.(12–14) A high-precision 3D model is the optimal and most needed data carrier to achieve comprehensive intelligent supervision.(15) In the general mine model, the monitoring data are processed, sorted, and summarized, which can reduce the workload of data processing. Therefore, the key direction for the modern management of a mine is to use a 3D model of the mine as a digital base and to use GNSS sensors to supervise the real-time positioning information and trajectory of the mine cars. The system supports the quantitative calculation of illegal mining height, area, square volume, and other information on the real 3D model. Information on mineral rights may be imported to build an electronic fence. Finally, the system determines whether there is cross-border mining of mine cars and produces automatic warnings. In addition, our study relies on a supervisory system and uses virtual simulation technology to build a teaching platform for the intelligent supervision of mines. The platform is used to train practitioners in the application of UAV remote sensing technology and GNSS technology. The research results show that the combination of UAV remote sensing technology and GNSS sensors improves the integration of multi-source monitoring data, enables online management and rapid sharing of data, and has a revolutionary impact on the intelligent supervision of mines. Moreover, the virtual simulation platform realizes the visualization of the entire process of mine supervision, which is very practical and has decided value as a teaching tool.

2. System Design

2.1 Overall framework

The comprehensive supervision system for mining is based on a real-scene 3D model combined with WebGL technology, GNSS technology, and Java programming language. It monitors the real-time tracking information on mining equipment and provides real-time alarms in case of boundary crossings. The system architecture consists of five parts: a basic layer, a data layer, a support layer, an application layer, and an user layer as shown in Fig. 1.

2.2 Functional design

The system features a modular design, and each module is connected through the same interface, which is convenient for system operation, management, and maintenance. The functions include data management, transboundary information management, and analytical tools. The data management function module includes the functions of data collection, processing, and import and deletion of the real-scene 3D model. The boundary-crossing information management module realizes the dynamic display of mine cars on the real-scene 3D model, deployment of 3D geo-fencing, and early warnings of boundary-crossing mining. The analytical module includes 3D volume calculation, square volume calculation, and multi-temporal model comparison as shown in Fig. 2.

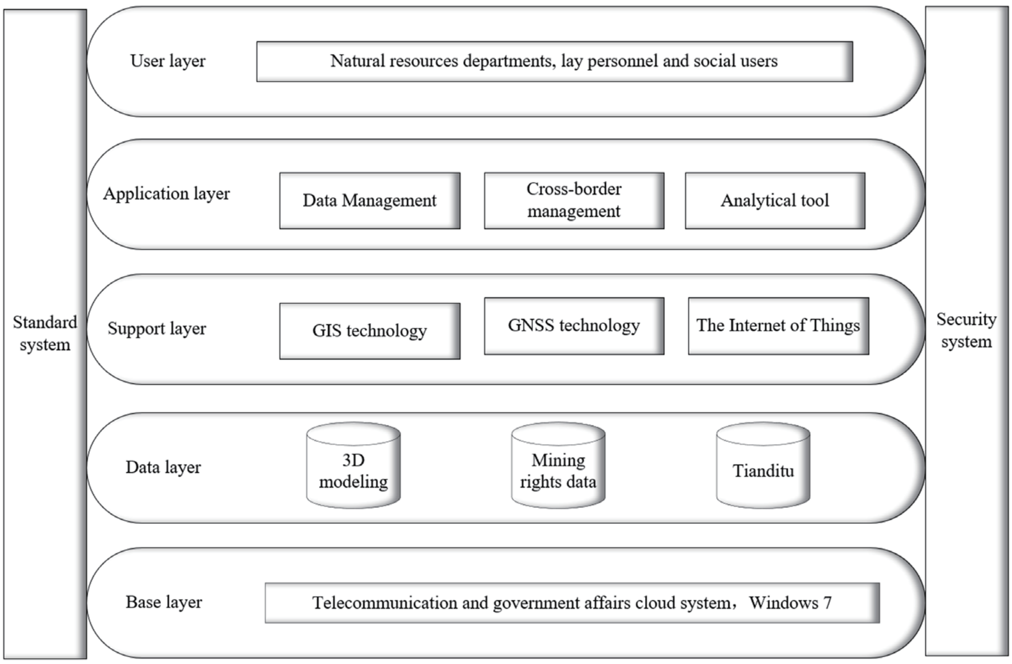

Fig. 1. Overall framework diagram.

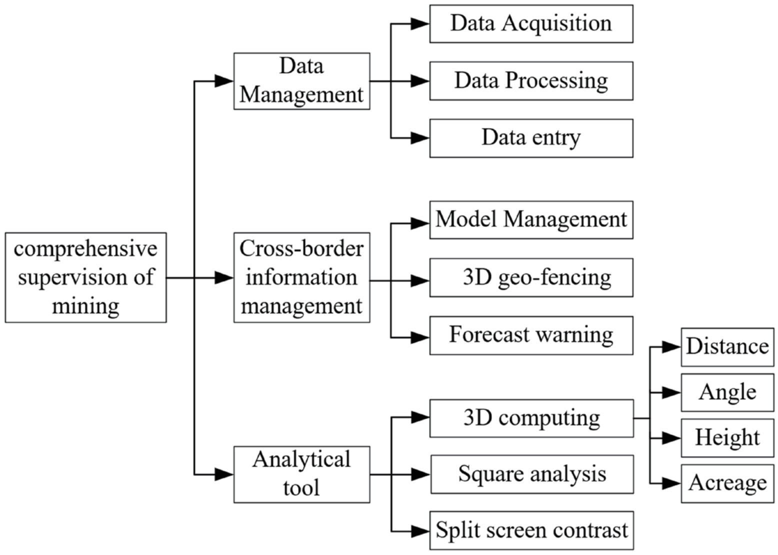

Fig. 2. Functional framework of the system.

3. Realization of Comprehensive Supervision of Mining

3.1 Data management module

3.1.1 Data acquisition and processing of 3D model

The UAV aerial images have the advantages of high definition, large scale, and presentability, as well as ease of operation and good stability.(16) Image data were therefore collected using Phantom 4. First, the operating area is planned on a map and the route is generated. The flight height is set according to the height of buildings in and around the survey area to ensure a safe flight. As this survey area is a sparsely built-up area, the heading overlap rate is generally set to more than 70%, and the collateral overlap rate is generally set to more than 80%, which improves the accuracy of modeling results. Finally, the UAV automatically performs the data acquisition task according to the planned route and acquires the image data with China Geodetic Coordinate System 2000 (CGCS2000) coordinate information, which lays a good foundation for the real-scene 3D modeling of the mine.

After the aerial photography was completed, we checked and pre-processed the collected image data, determining whether a shot was missed. and that the position and orientation system (POS) data were recorded in the corresponding image files, then used Context Capture software to process image data. The Context Capture Center Master software added the preprocessed image data, read the position information of the image automatically, checked the image file and carried out the aerotriangulation, constructed the three-dimensional grid, and mapped the textures. After the data processing was completed, a real-scene 3D model in OpenSceneGraph binary (OSGB) format was generated.

3.1.2 Data processing of mining rights

Owing to the differences between the issuing organizations of mining rights data, some data are expressed as 3-degree bands and some are 6-degree bands, so a corresponding coordinate transformation is needed. Because the mining boundary coordinates and models in mining rights data are the cartesian coordinates in space of CGCS2000, but the sky map uses latitudes and longitude as coordinates, it is necessary to convert all the coordinate data into latitude and longitudes. The 6-degree band coordinates are first converted to 3-degree band coordinates, and then the right-angle coordinate system of the 3-degree band is converted to latitude and longitude using a Gaussian inverse calculation to achieve a one-to-one correspondence between the two coordinate systems.

3.1.3 Data warehousing

According to the requirements of the system, the basic data for each mine needs to be sorted in a warehouse to realize centralized data storage management and retrieval. The mining rights data includes more than 100 data fields such as mine name, mine type, mining area number, mining situation, latitude and longitude, elevation, and license number, as shown in Table 1.

3.2 Cross-border management module

3.2.1 Model management module

This module is designed to facilitate the management of the mine area and the multi-temporal model under the same mine area. First, we take aerial drone photos of each mine site and build a real-scene 3D model, slice the model with the help of 3D tile technology, then import it into the system, manage the multi-phase model by grading and hierarchy, and finally display it on a website.

3.2.2 Electronic fence

On the basis of the real-scene 3D mine model, the module extracts the longitude and latitude of the mining area boundary, calls the function from the degrees array, and connects the points.

Table 1
Data dictionary.

Number	Field name	Field type
1	Mine Name	varchar(255)
2	Mine Type	varchar(255)
3	number	date
4	status	int(11)
5	longitude	double
6	latitude	double
7	height	double
8	Permit Nmb	varchar(255)

Finally, combined with the elevation data of the mine, the module sets up a 3D geographical fence, as shown in Fig. 3. In addition, alarm rules need to be added: for example, when a mining vehicle moves out of an electronic fence area, the system automatically records the crossing time.

3.2.3 Data on transmission of monitoring

The GNSS sensor is required to support forecasting and early warning. GNSS positioning equipment is installed on the mining vehicle to obtain real-time position information such as longitude, latitude, and elevation of the terminal on the vehicle; this location information is transmitted to the data center through a 4G/5G network, and the boundary of mining is judged by comparison with the 3D geographic fence. The location system sends out an alarm if over-border mining is identified. The principle of remote monitoring of mining is shown in Fig. 4.

This module is based on GNSS technology and is combined with Internet technology to transfer real-time positioning information to the system. To visualize the real-time track of the mine car, the system uses the real-scene 3D mine model and the 3D model of the mining vehicle. The system will automatically alarm and record the latest time and the number of violations if the mining vehicle exits the 3D geographic fence. The clues of violation are organized into a clue database to realize the real-time supervision of illegal mining in open-pit mines. The implementation flow chart is shown in Fig. 5.

The GNSS real-time positioning data is transmitted to the server via a 4G/5G network for data processing and then is judged regarding whether the vehicle is out of bounds. First, the flyLineFun function is called to define the coordinate array and to set the mining vehicle ID, ground route, and other properties. Then the function of startFly is used to make the vehicle start roaming, and finally, the function of checkPointIsInArea is used to determine whether the coordinate point is within the 3D geo-fence to judge whether the mining operation is crossing the boundary.

Fig. 3. (Color online) Electronic fence in a 3D mine model.

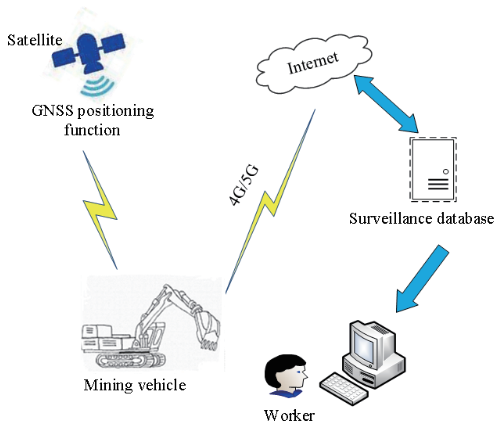

Fig. 4. (Color online) Principles of GNSS regulation.

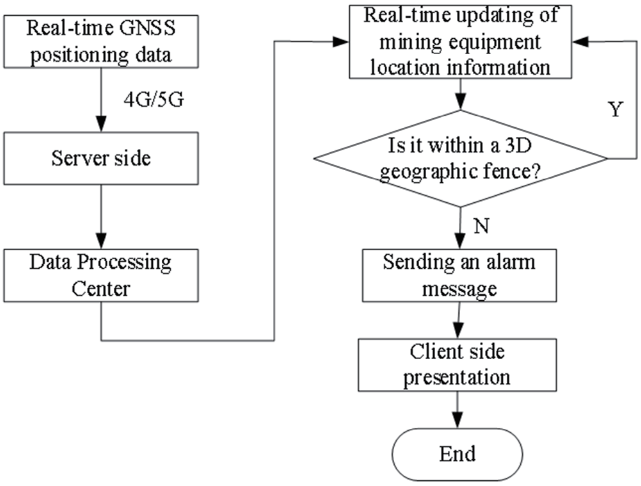

Fig. 5. Implementation process of the cross-border alarm service module.

3.3 Module for analytical tool

3.3.1 Three-dimensional calculations

On the basis of the Cesium framework, this module uses the actual 3D model of the mine as the base map to perform quantitative analyses such as the calculation of distance, angle, area, and height, all of which address the difficult problem of measuring the mine in the field. For example, the distance measurement can determine the width of the mine road and the width of the mining step surface to assess whether the mining is carried out in accordance with the development and utilization plan; the angle measurement can determine the slope of the mine pit, analyze the slope of the mine wall, and assess whether it is in line with safe production; the area measurement can determine the area of the mine pit and the scope of illegal mining; the height measurement can determine whether the mining is over the layer. By integrating various calculations, the operation efficiency may be greatly improved.

(1) The distance calculation is a Euclidean calculation; that is, it yields the distance L in meters. The equation is as follows:

$$L = \sqrt{\left(X_2 - X_1\right)^2 + \left(Y_2 - Y_1\right)^2 + \left(Z_2 - Z_1\right)^2}. \tag{1}$$

(2) The angle calculation involves selecting a data point as the origin of the coordinates that points to the North Pole of the Earth as a positive north direction; the instantaneous rotation in the direction of the included angle is α, and when $\alpha > 180°$, it is expressed as $\beta = \alpha - 360°$ as shown in Fig. 6.

(3) Area is calculated using the grid method as shown in Fig. 7; the equation is:

$$S = 0.1 \times 0.1 \times \left(m + n\right), \tag{2}$$

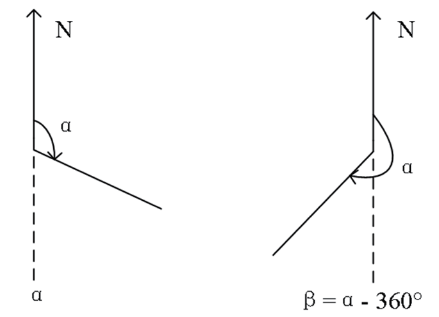

Fig. 6. Schematic diagram of angle measurement.

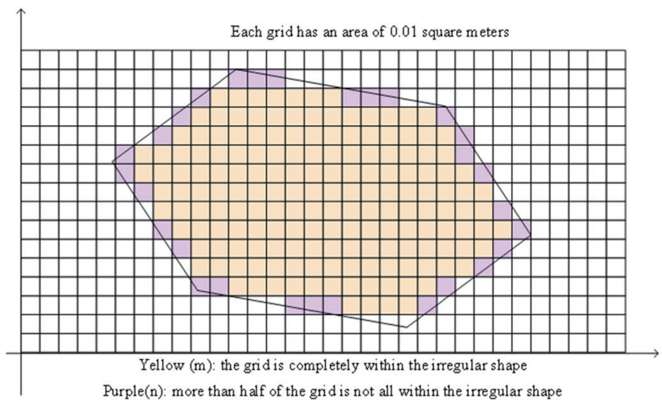

Fig. 7. (Color online) Schematic diagram of area calculation.

where m represents the total number of grids within the irregular figure, n represents more than half of the grid area, and S represents the area in units of square meters.
(4) There are two ways to measure height: first, because the Cartesian coordinate system points are in the same space, the difference in height can be obtained by subtracting the Z coordinates of the two points directly; that is, $H = Z_2 - Z_1$. Second, the difference in height can be calculated by triangulation as shown in Fig. 8. The equation is

$$H = L\sin\alpha. \tag{3}$$

3.3.2 Analysis of variance

The mining volume is calculated by using the measurement and calculation tools. According to the data on mining rights, the datum level and mining elevation are set in the square quantity calculation, so as to judge whether the production is in excess of scale, and the excess square quantity can be calculated, to provide the basis for the punishment of illegal mining. The square grid method is used for the analysis of variance, the equation is

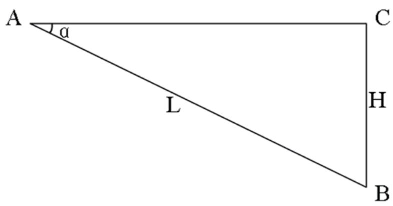

Fig. 8. Triangulation schematic.

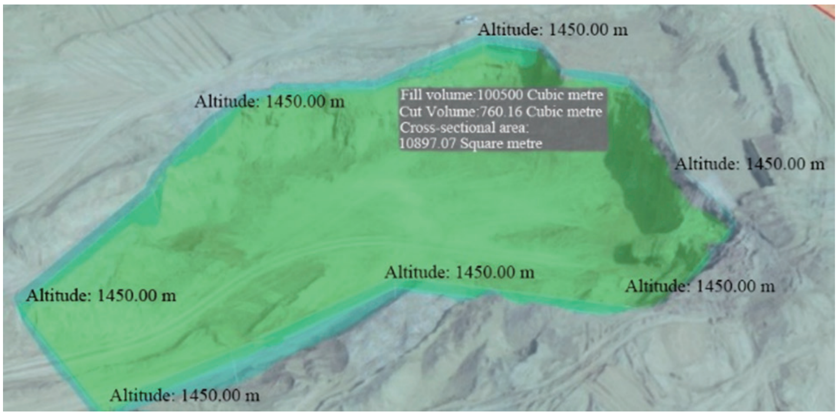

Fig. 9. (Color online) Diagram of calculation of area in m^2.

$$V = C \times (a + b). \tag{4}$$

The mining area is divided into a number of small cubes, where C represents a standard small cube's volume, and its value is determined by the model's accuracy. a means the number of small cubes that are completely inside the cube, b means the number of small cubes that make up more than half the volume of the small cube, and V means the volume of the mining area in m^3, as shown in Fig. 9.

3.3.3 Comparison of multi-temporal models

This module uses JavaScript to control the linkage between the 3D model and the base map. The model can be dragged and scaled synchronously. Regulators can quantitatively analyze changes in a mine, determine whether there are persistent violations, and improve efficiency. A comparison of a mine at different times is shown in Fig. 10.

3.4 Comparison with other measurement methods

Early research on monitoring mines with sensor technology used the GPS system to build the Internet of Things (IoT) base station and to connect with the internet system of the mining industry.[17] Some experts used DIMINE software to build 3D models of mines, integrated the

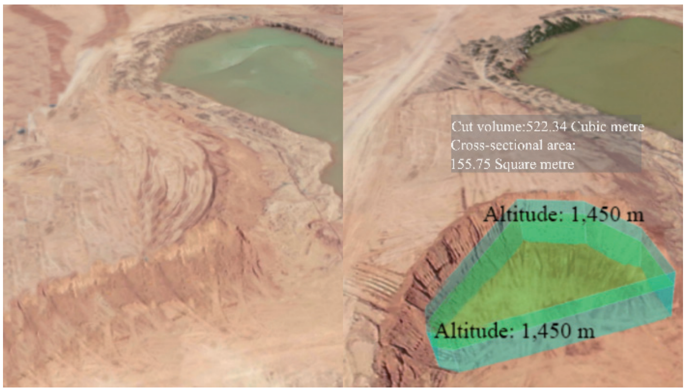

Fig. 10. (Color online) Comparison of mine in different times.

Table 2
Comparison with other monitoring methods.

Methods	GNSS technology and tilt photogrammetry of UAV	Wearable sensors and wireless LAN technology	PDA & DIMINE
Online visualization of real-scene 3D model	√	×	×
Electronic fence	√	√	√
Automatic alarm	√	√	√
Quantitative analysis	√	×	√
Virtual simulation teaching	√	×	×

models with personal digital assistant (PDA)-based geological resource data, and thereby achieved real-time supervision of mines.[18] With the development of IoT, the electronic fence came into being. Some studies have designed electronic fence systems based on wireless local area network (LAN) technology to provide feedback based on the monitoring of pulse signals.[19] Other studies have used wearable IoT and electronic fences to manage isolation because of outbreaks of disease.[20] This study uses UAV tilt photography technology and GNSS technology to construct 3D models, track real-time mine car trajectories, and provide early warning forecasts of cross-border mining behavior. Table 2 shows a comparison between methods used in this study and other methods of monitoring.

From Table 2, it can be seen that the method adopted in this paper can be used to construct real-scene 3D models of mining and as a digital base to realize the functions of 3D calculations and analysis of variance. In addition, this study uses virtual simulation technology to enable online teaching about the supervision of mining operations.

4. Application of Comprehensive Supervision of Mining

This system provides a stable platform for the work of a supervisory department, which directly oversees a system with a focus on monitoring whether mining is carried out in accordance with a development and utilization plan. The supervision includes observation of boundary-crossing mining and super-layer mining, taking the three-dimensional model of an actual mining scene and mining rights data as the base data, which is used to judge whether mining vehicles are crossing boundaries identified via the 3D geographical fence.

4.1 Automatic warning

The monitoring data is processed by the server and then fed back to the web page. When a mining vehicle crosses a boundary, the client receives an alarm. The mining vehicle displays the alarm status in a conspicuous way on the 3D model; for example, the background color turns red, and when the mining vehicle re-enters the electronic fence range again, the background color disappears automatically. At the same time, the system automatically refreshes the list of the number of crossing times and the latest crossing time. As shown in Fig. 11, tramcar No. 1 crossed the border four times, with the latest crossing occurring at 8:13 p.m. on 28 September 2022.

4.2 Analysis of overburden mining

By comparing the mining elevation data with the measured height of the pit, we can directly judge whether there is super-layer mining. The mining elevation values were 12.71 and 12.56 m, while the allowable mining height difference for this mine was 20 m. Therefore, there was no superstratum mining in this mine, as shown in Fig. 12.

5. Extending the Application of Virtual Simulation to Training and Teaching

The construction and application of a comprehensive supervision system for mining provides important technical support for accelerating the development of a green mining industry.

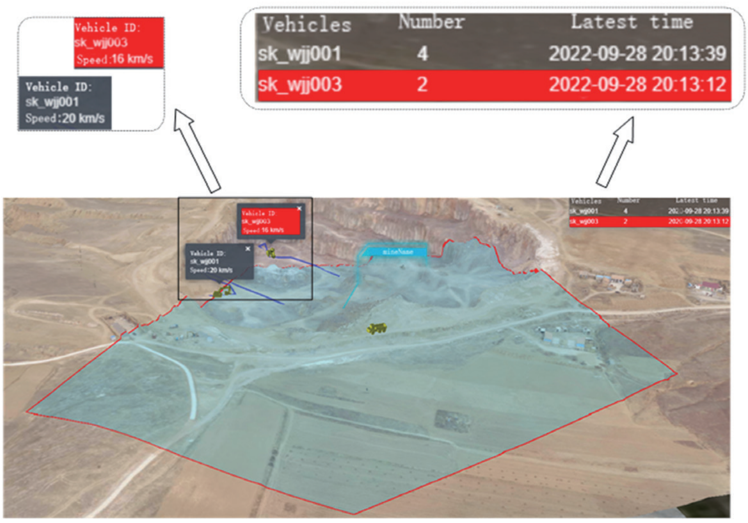

Fig. 11. (Color online) Cross-border warning.

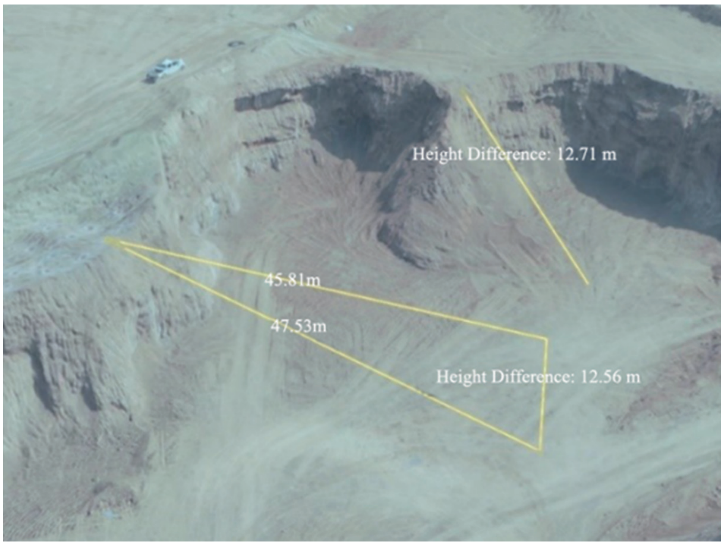

Fig. 12. (Color online) Analysis of overburden mining.

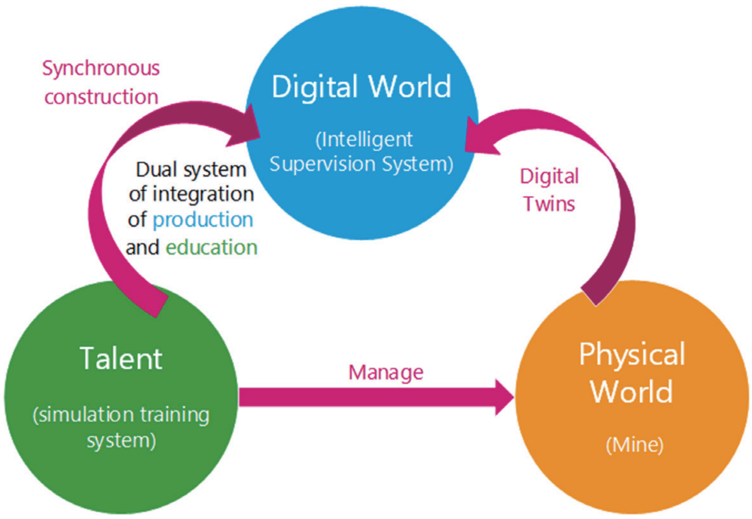

Fig. 13. (Color online) Dual system construction concept.

However, the experimental courses at domestic universities do not teach relevant applications, and offline teaching is likely to result in risks to personal safety and equipment damage. Therefore, we propose using the Enjoyhint framework to build a virtual simulation teaching system. The digital twin (a virtual copy of a physical product, process, or system) is used to build a mutually supportive dual system of industry-education integration to train more managers in the process of digital mine transformation. The dual system concept is shown in Fig. 13.

5.1 Design of a training and teaching system based on virtual simulation

5.1.1 Module design

The training and teaching system is divided into four modules: knowledge backpack, 3D data acquisition and processing, smart supervision of the mining application, and provincial-scale application planning. Figure 14 shows the design of the teaching module. Through virtual simulation experiments, students can safely and clearly carry out experiments on real-scene 3D acquisition, processing, application, and development of UAVs and learn about multi-source sensors such as video, device perception, and internet data in the fusion of 3D data.

5.1.2 Instructional design

This system uses the Enjoyhint framework to create action tips and provide the easiest way to create interactive tutorials and hints for web pages. It can also be used to highlight and sign application elements. The framework uses code to specify different events and execute the callback functions onStart and onEnd to implement callbacks. Through a preset operation, the students can understand the specific use of the system, points requiring attention, operational details, and other features relating to mining operations, all within an autonomous learning environment.

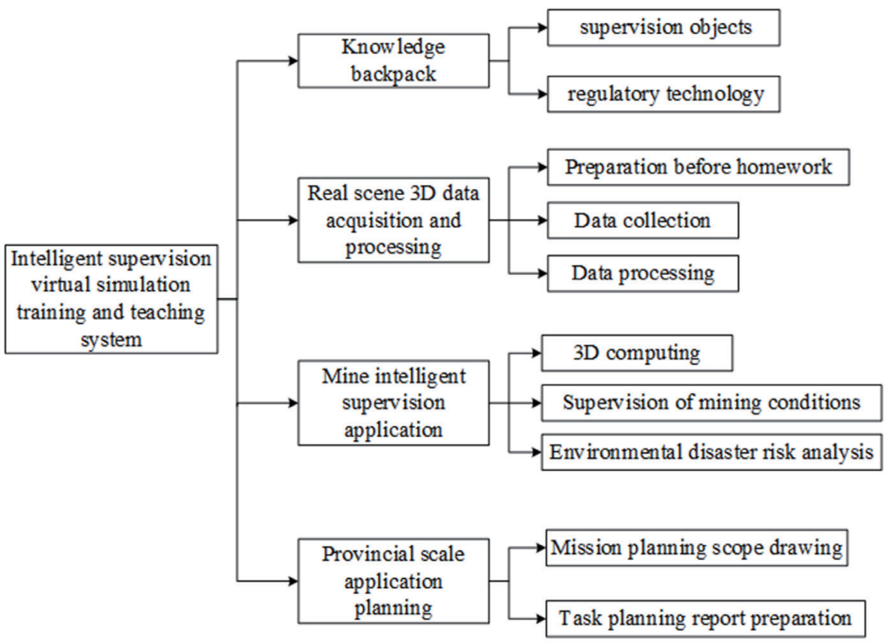

Fig. 14. Diagram of the module system for training and teaching.

5.2 Realization of a virtual simulation training and teaching system

5.2.1 Operation in 3D space

In interactive teaching, students gradually learn how to use the tools of the system to perform operations in 3D space, such as measurements on maps and analysis of squares on the real 3D model of the open-pit mine. Students can use measuring tools to mark points according to different distances, areas, and squares. After the marking is completed, the system automatically calculates the specific data. The use of human–computer interaction allows students to repeatedly operate and practice independently to achieve the educational purpose of the virtual simulation as shown in Fig. 15.

5.2.2 Training UAV data acquisition in the simulation

This module uses 3DS MAX software to build a high-precision UAV model and to replicate the entire process of 3D data collection and production carried out by drones based on WebGL technology. The virtual simulation experiment of UAV aerial photography is shown in Fig. 16. It can also compare the advantages and disadvantages of different take-off and landing points in the virtual mine scene, select the appropriate take-off and landing points for the UAV, assemble

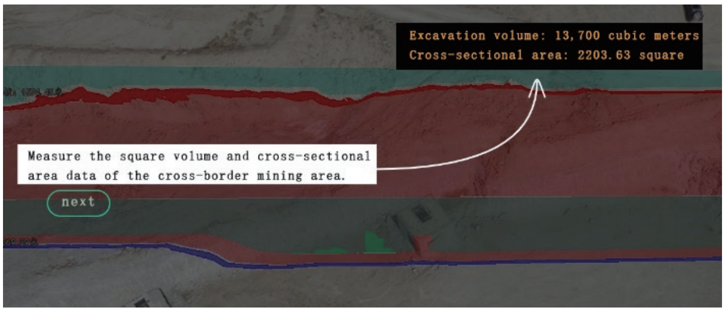

Fig. 15. (Color online) Teaching the operation for the analysis of squares.

Fig. 16. (Color online) Simulation of aerial drone photography.

the UAV equipment correctly, and simulate aerial photography. It makes the students clearly and intuitively understand the steps of real-scene 3D data production process and develop the ability of data modeling.

6. Conclusions

In this paper, we present an in-depth analysis of and research on applications in the intelligent supervision of mining and the use of virtual simulations in teaching. The use of UAV tilt photography technology to build a highly precise 3D model of a mine solves the problems of low accuracy and lack of timeliness of the model. The online square analysis function of the real-world 3D model solves the problem of traditional measurement that consumes labor and material resources. Compared with other research methods, the combination of UAV remote sensing technology and GNSS sensors has improved the integration of multi-source monitoring data, solved the problem of data silos, and realized the modernization of mine management. The system of training and teaching using a virtual simulation provides a network platform for training personnel in the applications of remote sensing technology and provides experience in promoting domestic digital teaching.

With the continuous construction and development of IoT, information integration based on multi-source sensors is definitely a key direction in the field of remote sensing. Although the system realizes real-time supervision of open-pit mines, remote monitoring of mining equipment in underground mines is yet to be studied. When that is achieved, artificial intelligence will be introduced to the design of automatic algorithms for calculating mining volume and to the task of building a model of an underground mine to realize the automatic identification of illegal mining processes.

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References

1 M. G. Zhai and B. Hu: J. Earth Sci. Environ. **43** (2021) 1. https://doi.org/10.19814/j.jese.2020.10018
2 R. Y. Long and J. H. Yang: Resour. Sci. **40** (2018) 465.
3 X. Jin, N. Kong, L. N. Guo, and S. P. Xu: China Min. Mag. **28** (2019) 29.
4 D. Kim, J. Youn, T. Kim, and G. Kim: Sens. Mater. **31** (2019) 3835. https://doi.org/10.18494/SAM.2019.2568
5 R. Sun, W. Y. Zhang, J. Z. Zheng, and W. Y. Ochieng: J. Remote Sens. **12** (2020) 524. https://doi.org/10.3390/rs12030524
6 J. K. Park and K. W. Lee: Sens. Mater. **32** (2020) 3853. https://doi.org/10.18494/SAM.2020.2911
7 M. Stroner, R. Urban, J. Seidl, T. Reindl, and J. Broucek: J. Remote Sens. **13** (2021) 1336. https://doi.org/10.3390/rs13071336

8 J. Zhang and Z. L. Nie: Coal Technol. **40** (2021) 209. https://doi.org/10.13301/j.cnki.ct.2021.10.052
9 E. J. Ding, X. Yu, B. Xia, X. H. Zhao, D. Zhang, T. Y. Liu, and W. D. Wang: J. China Coal Soc. **47** (2022) 564. https://doi.org/10.13225/j.cnki.jccs.yg21.1930
10 M. Kozielski, M. Sikora, and Ł. Wróbel: Data Brief. **39** (2021) 107457. https://doi.org/10.1016/j.dib.2021.107457
11 Monika, H. Govil, R.S. Chatterjee, P. Bhaumik, and N. Vishwakarma: Adv. Space Res. **70** (2022) 3905. https://doi.org/10.1016/j.asr.2022.05.018
12 W. Sun, L. Dai, X. R. Zhang, P. S. Chang, and X. Z. He: Appl. Intell. **52** (2021) 8448. https://doi.org/10.1007/s10489-021-02893-3
13 Y. X. Zhang, P. T. Lan, Y. C. Jin, L. Zhou, and Y. Y. Cui: Survey. Map. Bull. **S1** (2017) 114. https://doi.org/10.13474/j.cnki.11-2246.2017.0630
14 X. H. Liao, Q. Xiao, and H. Zhang: J. Remote Sens. **23** (2019) 1046. https://doi.org/10.11834/jrs.20199422
15 Y. R. He, P. Chen, W. W. Ma, and C. C. Chen: Sens. Mater. **32** (2020) 1743. https://doi.org/10.18494/SAM.2020.2692
16 P. K. Sharma and D. I. Kim: IEEE Trans. Wireless Commun. **18** (2019) 2527. https://doi.org/10.1109/TWC.2019.2904564
17 S. Z. Du, L. B. Zhang, J. S. Hou, and F. Z. Zhou: Met. Mine. **12** (2019) 150. https://doi.org/10.19614/j.cnki.jsks.201912026
18 M. J. Lian, Z. L. Wang, L. Ma, and H. J. Wang: China Min. Mag. **28** (2019) 122.
19 Q. Tang: Alexandria Eng. J. **61** (2022) 2959. https://doi.org/10.1016/j.aej.2021.08.019
20 U. Farman, U. H. Hassan, K. Jebran, S. A. Ali, A. Usman, and S. Lee: Electronics **10** (2021) 2035. https://doi.org/10.3390/electronics10162035

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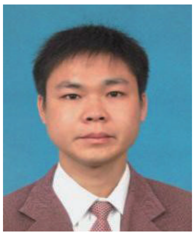

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