



# Application of Intelligent Identification Technology for Coal Mine Geological Structures in Downhole Directional Drilling

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**Abstract:** This paper explores the application of deep learning and multi-source data fusion technology in intelligent identification of geological structures. By constructing a real-time perception and decision-making system, it effectively enhances the precision and safety of underground directional drilling, providing reliable technical support for drilling path optimization and water hazard prevention in complex coal seam environments.

**Keywords:** coal mine geological structure, intelligent recognition, underground directional drilling

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## 1. Introduction

With the extension of coal mining to deep and complex geological conditions, traditional drilling methods are facing severe challenges in structural identification and real-time control. The introduction of intelligent identification technology reconstructs the geological perception system through a data-driven way, providing a new technical path for accurate and efficient underground drilling.

## 2. Core methods and principles of intelligent identification technology

The core of intelligent recognition technology is to build convolutional neural network model driven by deep learning algorithm to realize automatic feature extraction and intelligent classification and recognition of various types of underground detection data. By integrating and fusing multi-source heterogeneous data such as seismic reflection data, borehole lithology parameters, electromagnetic detection information, the technology first completes noise filtering and normalization processing in the data preprocessing layer. Subsequently, the system enters the feature extraction layer to accurately identify the unique texture features, waveform anomalies, physical property mutations and other key information of geological structures.

In the pattern recognition stage, the system adopts an improved ResNet network architecture to intelligently classify complex geological structures into different categories such as faults, folds, and collapse columns, and simultaneously outputs recognition results with confidence assessment. To meet the stringent real-time requirements of underground directional drilling, this technical framework introduces an edge computing unit, which can control the single data processing time to be within 15 s. Currently, the recognition accuracy of this technology has been stably maintained at over 91%, providing reliable and efficient geological information support for precise trajectory planning and real-time adjustment in underground directional drilling [1].

## 3. Application of intelligent identification technology in underground directional drilling

### 3.1 Accurate detection and drilling path optimization of fault fracture zone

In the underground directional drilling construction, the intelligent identification system establishes the fault fracture zone characteristic database by collecting the multi-dimensional parameters such as vibration waveform, torque change rate and debris particle size distribution during the drilling process in real time. The system is equipped with triaxial acceleration sensor and torque sensor on the drill pipe, and the drilling dynamic parameters are continuously obtained at 20Hz sampling frequency. At the same time, the seismic detection while drilling module is configured, and the elastic wave generated by the drill bit breaking rock is used for advanced detection in the range of 30~50 m in front. The system takes the variance of drilling torque fluctuation  $\sigma^2$  and the first arrival time difference of seismic wave  $\Delta t$  as the key discrimination indexes, and triggers the early warning mechanism when the discrimination conditions are met. The calculation formula of the probability value of fault fracture zone is:

$$P_{fault} = \frac{1}{1 + e^{-\alpha \cdot \sigma^2 + \beta \cdot t - \theta}} \quad (1)$$

In the formula,  $P_{fault}$  is the probability value of fault fracture zone,  $\alpha$  and  $\beta$  are weight coefficients, which are determined by regression analysis of 286 groups of fault drilling data, and  $\theta$  is the threshold parameter. When  $P_{fault} > 0.75$ , the system automatically calls the path optimization algorithm, calculates the detour scheme based on the three-dimensional geological model and real-time drilling trajectory data, and generates complete guidance instructions including horizontal displacement, vertical adjustment amount and build slope change curve [2].

According to the identification results of the width of the fractured zone, the risk level is divided into three categories: Level I (width < 2m) adopts the speed reduction crossing strategy, the speed is reduced to 180~220r/min, and the WOB is controlled at 8~12kN; level II (width 2~5m) executes small angle detour, and realizes 3~5 ° track offset by adjusting the tool face angle; For level III (width > 5m), start the large range avoidance mode, re plan the drilling path in combination with the geological model, finish the hole in advance and adjust the drilling site position if necessary.

### 3.2 Real time monitoring of coal seam occurrence and improvement of drainage effect

The intelligent identification system synchronously analyzes the logging data while drilling during the drilling process, and uses the natural gamma detector, dual laterolog and acoustic logging tool installed in the drilling tool to collect the formation physical parameters at the frequency of 5~10Hz. The system denoises the original data through Kalman filter algorithm, eliminates the interference signals caused by drilling tool vibration and irregular borehole wall, and then inputs the natural gamma curve, resistivity gradient and coal seam thickness change rate into convolutional neural network model to evaluate the occurrence of coal seams[3]. Table 1 shows the measurement performance and drilling control response parameter configuration scheme of the system under different geological parameters.

**Table 1. Geological parameter analysis and drilling control parameters of intelligent identification system**

Geological Parameter Type	Measurement Frequency (Hz)	Data Processing Delay (s)	Feature Extraction Dimension	Recognition Threshold	Drilling Response Adjustment Range
Natural Gamma Intensity	10	2.3	8	±15 API	Rotation Speed ±25%
Resistivity Change Gradient	5	3.1	12	300 Ω·m/m	Drill Pressure ±18%
Acoustic Time Difference Fluctuation	8	2.8	10	25 μs/m	Azimuth ±3°
Cuttings Particle Size Distribution	Continuous	4.5	6	Proportion of particles >8mm reaches 30%	Pump Pressure ±22%
Drilling Torque Variance	20	1.2	5	σ² > 45 N·m²	Penetration Rate ±35%

The system uses the dynamic window sliding algorithm to track the coal seam boundary in real time, sets the analysis window with a length of 15 m, slides forward in 3 m steps, and determines the position of the coal seam interface by calculating the Euclidean distance of the physical parameters of adjacent measuring points. The calculation formula of the boundary discrimination distance is:

$$D_{boundary} = \sqrt{\sum_{i=1}^n w_i (X_i - X_{i+1})^2} \quad (2)$$

In the formula,  $D_{boundary}$  represents the boundary discrimination distance,  $w_i$  denotes the weight coefficient of the  $i$ th parameter, with the weights of natural gamma, resistivity, and sonic time difference set to 0.42, 0.35, and 0.23 respectively.  $X_i$  signifies the parameter value at the measurement point. When  $D_{boundary}$  surpasses the preset threshold of 0.38, the system determines that the coal seam interface has been penetrated and automatically generates a trajectory adjustment command. By adjusting the deflection rate, the borehole is guided back into the coal seam.

### 3.3 Advanced warning and water hazard prevention for concealed water-conducting structures

The intelligent recognition system can establish a multi-parameter collaborative early warning mechanism for concealed water-conducting structures. By monitoring hydrogeological parameters such as borehole water inflow, water pressure change rate, and surrounding rock water saturation in real-time during drilling, and combining transient electromagnetic detection data, a risk assessment model for water-conducting structures is constructed. The system is equipped with a micro water pressure sensor array at the front end of the drilling tool to collect dynamic water pressure information in the borehole at a frequency of 2Hz. When the water pressure gradient exceeds 0.08MPa/m, a deep learning network is activated for abnormal pattern recognition [4].

In addition, the system inputs 12 characteristic parameters such as low resistivity abnormal area, drilling parameter mutation point, and hydrochemical ion concentration into the support vector machine classifier, and realizes the automatic recognition of structural types by establishing the discrimination hyperplane of five types of water conducting structures, such as collapse column, karst fracture, and water bearing fault. Table 2 shows the response characteristics of system monitoring parameters and the configuration of prevention and control measures under different types of water conducting structures.

**Table 2. Comparison of intelligent identification parameters and control measures of concealed water conducting structures**

Water-Conducting Structure Type	Apparent Resistivity( $\Omega$ -m)	Water Pressure Gradient (MPa/m)	Water Inflow( $m^3/h$ )	Early Warning Distance(m)	Detection Accuracy(%)	Grouting Hole Count (units)	Grouting Volume ( $m^3$ )
Karst Fracture Zone	45~120	0.12~0.28	3.5~8.2	18~25	87.6	5~8	12~18
Subsided Column	80~180	0.15~0.35	5.8~15.3	22~32	91.2	8~12	25~42
Water Bearing Fault	35~95	0.09~0.22	2.1~6.7	15~28	89.4	4~7	8~15
Sandstone Fissure Water	150~280	0.06~0.14	1.2~4.5	12~20	85.3	3~5	5~11
Goaf Water Accumulation Area	20~65	0.18~0.42	8.5~22.6	25~38	93.8	10~15	35~65

For high-risk hydraulic structures such as collapse columns, the system uses time series analysis method to predict the trend of hydrological parameters in the drilling process. When the water inflow of five consecutive measuring points increases exponentially and the growth rate exceeds 35%, the system automatically triggers a three-level response mechanism: the first level response immediately reduces the drilling speed to 0.3m/min and increases the mud density to 1.25g/cm<sup>3</sup>; The secondary response starts the grouting system in the hole and injects cement water glass double liquid slurry into the front structure through the embedded grouting pipeline for pre reinforcement; The three-level response calls the transient electromagnetic instrument for 360°omni-directional scanning, and draws the three-dimensional resistivity distribution within 50m in front of it, providing accurate spatial positioning information for the grouting borehole layout and curtain water stop scheme design [5].

## 4. Conclusion

Intelligent identification technology has significantly improved the geological adaptability and intelligent decision-making level of underground drilling. In the future, multimodal data fusion and adaptive algorithm optimization can further promote the development of unmanned and accurate coal mine drilling.

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