In all kinds of production, the changes of the times and scientific and technological progress make us have higher requirements for monitoring data. In order to improve the accuracy of mine rock microseismic monitoring and the sensitivity and specificity of mine disaster early warning, it is very important to use the change of light and material vibration to monitor environmental changes. This paper is the design of an optical hardware system, which improves the traditional system, uses the change of light wave to detect the spatial change, and forms a nano digital imaging photography (NDIP) system to collect more detailed data. The three-year field experiment under the guidance of a simulation experiment shows that the system has higher monitoring sensitivity, early warning sensitivity, and specificity than the laser gyroscope system, but its antidust interference ability is low, so it cannot replace the laser gyroscope system in a short time, but it can supplement and realize data fusion analysis.

1. Introduction

All kinds of mines, resource mining of coal, iron, manganese, or nonferrous metals, open-pit mining, underground mining, or continuous small-scale mining methods, will bring continuous and irregular disturbance to the surrounding rock. [1] The microseismic process of surrounding rock caused by these disturbances is difficult to be effectively detected by a conventional seismograph, but it interacts with the natural process of rock pressure, which is easy to cause accidents such as collapse, water gushing, and gas outburst. [2] Therefore, in recent years, the research in the field of intelligent mine has developed rapidly, and the research on mine microseismic detection instruments has also been kicked out of new requirements.

Nano digital imaging photography (NDIP) technology was first applied to explosion research. A certain amount of explosives are detonated on the parallel light propagation path, and the air density disturbance caused by the explosion shock wave will form an image change on the imaging element. [3] Because the air interference energy required in this study is far greater than the energy generated by the mine micro on the air medium in the mining area, a method to effectively capture the mine microseismic characteristics is formed by using ndip technology and multiband interference imaging method, which realizes the accurate learning and analysis of wave characteristics in field experiments [4].

The core innovation of this research is to transform the complex rock shock wave under the microaction of the mine into the spatial relationship change signal of the inner wall of the tunnel, then use the optical instrument to capture the spatial relationship change process, introduce the machine learning algorithm to identify and analyze the items without the feature library, and introduce the machine learning algorithm to identify and analyze the items without the feature library. [5].

This study will compare the NDIP technology with the traditional monitoring and early warning system, analyze
the advantages and disadvantages of various technologies, improve the NDIP system, and complement the traditional technology to expand the scope of use.

2. Optical Hardware System Design of NDIP

On the basis of the traditional NDIP system, spectroscope system, vibration mirror system, and optical interference system are introduced, and the interference image is collected, which avoids the imaging process that traditional ndip needs large energy to disturb the medium density to obtain an effective image. The base of the vibration mirror is fixed on the tunnel rock wall structure, and the rock wall structure has an amplitude of 1/4 of the light wave wavelength in space, which can cause a large range of image changes in the optical interferometer. The above system is shown in Figure 1.

In Figure 1, the light source system formed by the light-emitting component, lens component, and beam splitter component is used as system A, the two reflector systems are used as system B and system C, and the interferometer component and imaging component are used as system D. Relatively stable optical paths can be formed in the four systems through truss structure and object structure, but the four systems need to be installed at a long distance in the tunnel, so this installation method can make each system to form a long and integral support structure under the combined action of elastic-plastic deformation. Therefore, when the final imaging results change, it is not only the separate spatial interference of the a-b-d path or a-c-d path but also the displacement disturbance of system A and system D itself. That is, although the improved NDIP system can sensitively capture the spatial deformation of 1/4 wavelength, it is disturbed by strong vibration, and the machine learning analysis system needs to effectively eliminate this interference.

In order to determine the monitoring wavelength provided by the light source, the vibration amplitude of mine rock mass microseism is counted, and Figure 2 is obtained.

In Figure 2, the amplitude probability of rock mass vibration amplitude is widely distributed between 0~1500 nm (0 ~ 0.0015 mm). According to the interference principle, when the phase displacement of the lightwave exceeds 1/4 wavelength, the interference provisions will change most significantly; that is, the bright lines will be completely transformed into dark lines. The wavelength range of visible

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**Figure 1:** Optical device logic of improved NDIP system.

**Figure 2:** Statistical table of occurrence probability of rock mass vibration amplitude.
light is 390–780 nm. The operable wavelength range of general light source and optical probe based on a photosensitive system includes visible light, near-infrared, and near-ultraviolet; that is, optical interference images can be effectively collected in the range of 220–1350 nm. The actual vibration amplitude of the rock stratum is also widely distributed within the range of 1500 nm above the figure, which is not within the control range of the system. Other probes can be used to help capture vibration signals.

In the actual wavelength selection, the system uses 235 nm near-infrared ray as red light (adjusted to 650 nm after imaging), with 520 nm green laser as a green light, and 1300 nm near-ultraviolet as blue light (adjusted to 425 nm display after imaging). As mentioned above, the detection range of the digital photosensitive negative is 220–1350 nm. Too close to the two-stage limit of digital photosensitive negative will affect the photosensitive efficiency. Therefore, 235 nm, 520 nm, and 1300 nm within this range are selected as photosensitive targets for monochrome imaging, respectively.

3. Digital Processing Strategy of Microseismic Image

In this study, three wavelengths are used to form the detection scale, which are 235 nm, 520 nm, and 1300 nm, respectively. Each light wave produces significant measurement points at 1/4 wavelength, and sliding measurement can be realized; that is, the three columns of detection scales are 58.75 nm, 130 nm, and 325 nm, respectively. After the three columns of scales are overlapped, the minimum common multiple is 3770 nm, and the minimum common divisor is 1.25 nm; that is, the maximum economic range of the composite measurement scale is 3770 nm (0.00377 mm), and the maximum measurement error is ±1.25 nm. The signal exceeding 3770 nm (0.00377 mm) will need to be measured repeatedly by using the counter because it crosses the common multiple ranges. Subject to the length, this measurement scenario will not be discussed here.

In Figure 3, the raster images obtained by the three wavelength probes are integrated to form a color image with a resolution of 1024×768 pix. After spatial convolution by the peak detection convolution core and edge detection convolution core, the peak-enhanced image and edge-enhanced image are formed with a resolution of 1024×768 pix; that is, the two enhanced images contain 786432 data sections. During the convolution process, when each point experiences a peak, a counteraction is triggered to form a counterimage with the same resolution of 1024×768 pix. Three groups of enhanced images and counter images of 786432 data nodes are input into a 3-column multicolumn fuzzy neural network for data fuzzy convolution to form evaluation values on 3 [0,1] intervals. The structure of a 3-column multicolumn fuzzy neural network is consistent. Machine learning training is carried out according to different training objectives until its output results converge to the [0,1] interval. The data logic of a single-column fuzzy neural network is shown in Figure 4.

In Figure 4, using the depth fuzzy convolution algorithm, the 786432 data nodes given in each image input module are convoluted layer by layer to form a double-precision variable, and the three double-precision variables output by the three depth fuzzy convolution modules form a depth convolution flag carrying all the information of the above three image input modules after logarithmic iterative convolution. After machine learning and training, the value range control of the above flag value is compressed to the [0,1] interval. The closer the value is to 1.000, the greater the corresponding risk is considered. The closer it is to 0.000, the smaller the corresponding risk is considered.

In the depth fuzzy convolution module, the polynomial iterative convolution function is used for node design, and its basis function is shown in the following formula:

\[ F(x) = \frac{1}{1 + e^{-ax^2}} \]

Figure 3: Data logic architecture diagram of microseismic monitoring data processing system.
where $x_j^i$ is the $j$-th power value of the $i$-th input value; $n$ is the total number of data nodes of the previous neural network architecture; $A_j$ is the coefficient to be regressed of the $j$-th order polynomial; $y$ is the output value of the node.

In the logarithmic iterative convolution module, the logarithmic iterative convolution function is used for node design, and its basis function is shown in the following formula:

$$y = \sum_{i=1}^{n} \sum_{j=0}^{5} A_j x_j^i,$$

where $x_j^i$ is the $j$-th power value of the $i$-th input value; $n$ is the total number of data nodes of the previous neural network architecture; $A_j$ is the coefficient to be regressed of the $j$-th order polynomial; $y$ is the output value of the node.

In the logarithmic iterative convolution module, the logarithmic iterative convolution function is used for node design, and its basis function is shown in the following formula:

$$y = \sum_{i=1}^{n} (A \cdot \log x_i + B),$$

where $A, B$ is the coefficient to be regressed; $x_i$ is the $i$th input value; other mathematical symbols have the same meaning as formula (1).

4. Simulation Test of Improved NDIP System

The Simulink control is loaded into the mine pressure CAE system to build the simulation environment. The random number simulator is used to cooperate with the mine pressure event generator to generate mine pressure problems such as gas, water gushing, and instantaneous high bottom pressure. [6] The simulation system of the system is deployed in the tunnel model to carry out the following two experiments.

Firstly, the influence of the distance between the two vibrating mirror modules on the measurement accuracy is compared, as shown in Figure 5.

In Figure 5, different mirror spacing has a significant impact on the measurement accuracy, and there are certain differences in the high-precision measurement distance under different measurement requirements. When deploying the system, it is necessary to consider a certain compromise distance range, and considering the narrow space in the tunnel and the need for an unobstructed field of vision between optical measurement modules, the smaller the distance in the given accuracy range, the less difficult it is to deploy and manage. The figure shows that when the mirror spacing is 25~44 m, it is the economic installation distance.

Secondly, the influence of the installation offset distance between the light source and the grating on the measurement accuracy is analyzed. According to the analysis of Marius law in optical principle when the light beam propagates in an isotropic uniform medium, it always maintains the orthogonality with the wave surface, and the light path between the corresponding point of the incident wave surface and the outgoing wave surface is a fixed value, so the light source and grating shall be located in the middle of the two mirrors but affected by the size of electrical and mechanical components, and considering the influence of explosion-proof shell and other mechanical structures, the distance between the light source and grating shall be at least 550 mm. In order to ensure that their vibration interference effects are consistent, they must be completely fixed with the...
same set of rigid truss. By analyzing the monitoring accuracy under different distances, Figure 6 is obtained.

In Figure 6, if the measurement accuracy at the spacing of 550 mm is defined as 100%, the accuracy of the three early warning monitoring will have a sharp falling edge after reaching a certain distance. Therefore, in order to improve the monitoring accuracy, the spacing between the light source and the grating should be shortened to the greatest extent. Under the current technical conditions, 550 mm spacing is the best option. With the further development of technology in the future, the spacing should be further compressed.

From the perspective of system data source and data composition, the influence of the above distance factors on measurement accuracy is analyzed. It comes not from the wavelength of lightwave or from the vibration amplitude of rock mass, but from the wavelength of the sound wave. The power intensity of different sound sources in rock layers is also different. Therefore, the wavelength of sound waves in rock layers is very different mainly distributed at the wavelength of 80—150 m, but all possible sound waves have a wider range of wavelengths, which may occur at the lowest of 8—10 m (ultrasonic wave) and up to 2000—4000 m (infrasound wave). This research focuses on the control of sound waves with wavelengths of 80—150 m.

The extinction ratio and detector noise are two important parameters that determine [7] the polarization accuracy of nanowire gate polarization imaging. The mathematical model of two parameters and the relationship between the two parameters and polarization noise are established to solve the value problem of two parameters in system optimization. Simulation analysis compares the effect of two parameters on the polarization noise when the polarization state of incident light changes. Then, the precision experimental platform of the polarization imaging system with adjustable extinction ratio and exposure time is built to verify the mathematical model and simulation results. Simulation and experiments show that by increasing the number of photoelectrons received by the image tuple to suppress the detector noise, the extinction ratio of the system can be greater than 20 so as to improve the polarization accuracy of the system [8].

5. Application Scenario and Field Experimental Results of NDIP System

If the system is installed near the mining face or heading face, because it is an optical instrument, the measurement accuracy may be affected by dust. [9] Therefore, the system is generally installed on the stable rock roof of the fresh air tunnel. Because this method is far away from the mining face or heading face, and the relevant vibration has been attenuated for a long distance after being transmitted to the installation position, it has a great impact on the system accuracy and puts forward higher requirements for the system sensitivity [10].

In July 2018, the system was installed in the fresh air tunnel in a mining area of a coal mine for a field trial experiment. Since the commissioning and installation, the mining area has 1—2 mining faces and 3—5 heading faces. The goaf has developed from 990000 square meters in 2018 to 1.47 million square meters at the time of publication. The maximum radius of equipment control measurement is 2400 m.

During the trial period, a set of rock stratum vibration capture systems based on a laser inertial gyroscope is reserved in the system. The rock stratum vibration information provided by the system is used as comparative data to analyze 12435 manual blasts (including 71 large equivalent manual top caving blasts), 276 working face periodic pressures, 45 support pressure relief accidents, 65 flood peaks during the experimental time, and 92 gas emission peaks. Table 1 is obtained after statistics of relevant data.
In Table 1, the monitoring sensitivity of the early system based on laser inertial gyroscope is 84.78%~97.18%, the monitoring sensitivity of the monitoring system based on nano microseismic imaging technology designed in this study is 97.78%~100%, and the minimum sensitivity of the system designed in this study is still higher than that of the early laser inertial gyroscope system. Compared with the inertial system, the nano imaging system designed in this study is 11.10%, 2.90%, 7.91%, 7.32%, 10.34%, and 15.38% higher than that of the inertial system.

Based on the same experimental environment and data sources as the above experimental environment, 45 mine pressure accidents, 12 water gushing natural disasters with a water gushing volume of more than 1200 m³/h, and 18 gas gushing natural disasters with a gas gushing volume of more than 800 m³/h are analyzed. (V_hesensitivity and specificity of the three systems are compared, as described in Table 2. In Table 2, the specificity and sensitivity of the new system based on nano microseismic system are improved compared with the early system using laser inertial gyroscope. Sensitivity refers to the proportion of true positive data in all positive data, and specificity refers to the proportion of true negative data in all negative data.

By comprehensively comparing the statistical data in Tables 1 and 2, and investigating the simulation experiment and system working principle, the following three trial results can be obtained.

(1) The measurement principle of the laser gyro system and nano image system used in this study is to use the phase change of light wave to measure and monitor the small change of spatial scale. However, the measurement target of laser gyrooscope is to measure the acceleration of the anchor point, that is, to measure the inertial force on the anchor point during vibration. The system directly measures the distance change of spatial scale. Therefore, the measurement target of the mine microseismic system based on nano imaging designed in this study is more direct, and the data verification link from acceleration to scale is reduced. A simpler algorithm improves the reliability of the algorithm.

(2) The nano imaging probe designed in this study has a measurement accuracy of ±1.25 nm, which is much higher than the inertial force measurement accuracy of the laser gyrooscope; that is, the system error of the system is less than the minimum system error of the laser gyrooscope, which also leads to the actual measurement effect of the system is better than that of the laser gyrooscope system.

(3) The nano micromeasurement system designed in this study also has inherent defects. Subject to the limited space in the tunnel, the system cannot provide sufficient distance between mirrors; that is, it cannot control the mirror distance at the minimum common multiple lengths of all common mechanical wavelengths, resulting in the failure to achieve the overall highest accuracy for common mechanical waves in its actual operation state. However, experiments show that even subject to the installation conditions, the system still has higher adaptability under the demand of intelligent mine monitoring than the laser gyrooscope system.

### Table 1: Statistical comparison of monitoring sensitivity.

| Comparison items                  | Total | Inertial system | NDIP system |
|-----------------------------------|-------|-----------------|-------------|
|                                  | Number | Rate (%)            | Number | Rate (%) |
| Blasting event                   | 12435  | 11052 88.88%     | 12279  | 98.75%   |
| Large equivalent blasting event   | 71     | 69 97.18%        | 71     | 100.00%  |
| Rock periodic pressure           | 276    | 253 91.67%       | 273    | 98.91%   |
| Support pressure relief accident | 45     | 41 91.11%        | 44     | 97.78%   |
| Flood emission peak              | 65     | 58 89.23%        | 64     | 98.46%   |
| Gas emission peaks               | 92     | 78 84.78%        | 90     | 97.83%   |

### Table 2: Statistical comparison of sensitivity and specificity of natural disaster early warning.

| Comparison items                  | Inertial system | NDIP system |
|-----------------------------------|-----------------|-------------|
|                                  | Sensitivity (%) | Specificity (%) | Sensitivity (%) | Specificity (%) |
| Support pressure disaster         | 91.11           | 93.25        | 97.78          | 97.42          |
| Flood disaster                    | 90.27           | 92.17        | 98.27          | 98.11          |
| Gas disaster                      | 91.28           | 92.86        | 96.52          | 97.35          |

6. **Summary**

The ndip system for explosive wave measurement is introduced into the grating interference optical system to form an improved nano imaging system. [11] The ndip system designed in this study can be used to capture the rock microseismic signal in the mine, realize the real-time monitoring and early warning of rock pressure, rock gas, and restricted groundwater, and realize the innovation of the mine monitoring data system. [12] In any case, technological innovation and emergence can greatly increase the accuracy of data and effectively reduce the harm caused by mine earthquakes to people. [13] Perhaps, in the near future, this technology can be applied to buildings to ensure more life safety.
Data Availability

The data underlying the results presented in the study are available within the manuscript.

Conflicts of Interest

The authors declare that they have no potential conflicts of interest in our paper.

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