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Application of Mine Micro-Seismic Monitoring System on Preventing Against Illegal Mining

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Abstract

The establishment and application of the Mine Micro-seismic Monitoring System (MMS), provides a powerful method not only to monitor and predict the mine geological hazard, but also to monitor and prevent against the illegal mining. While there was illegal mining, the system can give you the information including the 3-dimensional spatial coordinates in real time. The monitoring against the illegal mining was aimed at the blast events, so the blast events should be collected and analyzed specially. On the other hand, the energy of the blast events are larger enough to be easily recognized and be 3-d located and then be analyzed by the MMS, and then the satisfied information can be given by the MMS. This kind of usage of the system has been analyzed and confirmed by a practical example.

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Keywords: Mine Microseismic Monitoring System, three dimensional location, realtime monitoring, prevent against the illegal mining

Introduction

With the increasing application of the Mine Micro-seismic Monitoring System in Chinese national wild, the research and realization of the system, including its principle, structure, standardization, demodulation and multiplexing techniques, has been developed deeply and wildly, and contributed more to ensure safety in mining production. To the early import systems, Chinese researchers have also done a lot in product

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localization, and developed a lot of auxiliary functions according to the Chinese situation. The function of monitoring against the illegal mining and the function of providing aid after disasters are good examples of this aspect. The current situation, that many mine safety accidents was happened and it leads to construct the technical supporting system for mine work safety in the country. Though safety supervision of all levels and mine owners have done much to prevent accidents, there still many mine accidents occurred. Therefore, mine emergency rescue system should be further improved. Considerable attention has been directed toward seismic activity in the mine by a MMS (Micro-seismic Monitoring System). It can obtain the stress variation law and deformation rule of rock mass, therefore. it also can help to predict the mine geological disaster such as rock burst, water inrush. The relationship between strata fracturing and rock burst in underground coal mine was studied by Jiang [1], the application of micro-seismic monitoring technology on underground projects was described by Li [2]

1. Basic description of the Mine Micro-seismic Monitoring System

1.1. Basic principle of Micro-seismic Monitoring System

It was known that stress concentrates inside the solid mass where there were some shortage or anisotropic zones, while it under external force, and the stress concentration will cause micro-cracking's creation and its expansion, and the strain energy accumulated releases rapidly at the same time. Accompany with the energy releasing, a kind of stress-wave was produced, named Acoustic Emission (AE) . Scholars such as Chun'an Tang[3] believe that the AE of rock is micro-seismic pulse produced during the period of the rock breaking, has a direct relationship with the rock internal micro-cracks and faults whose development and expansion leads rock damage. So there is a direct relationship between the AE and the evolvement of rock internal faults and cracks, and the information of rock damage can got from AE signals [4].

1.2. MS events location techniques

1.2.1. Events location techniques overview

The techniques for determining event location from P-wave arrival times can be divided into two categories: point location techniques and zonal techniques. Point location techniques, which were most widely applied, attempted to estimate the exact coordinates of the event, while zonal techniques define zones of activity based on the ordering of arrivals .The point location techniques can be further classified into two groups, direct methods, such as least squares fitting of time residuals (both linear and quadratic forms), and indirect methods, such as iterative techniques that arbitrarily determined test locations and converge, by dimishing error to a minimum. Mixed methods, combining direct and indirect techniques, were often considered to be iterative techniques. The essential aspect of these techniques were that the errors were minimized between the observed and calculated arrival times, and converge to a solution. The mapping of errors associated with different points in three-dimensional space for an array-source combination, was referred to as the error space [5-7].

There were three kinds of methods often used in MS-systems for locating events, named Simplex method (iterative), the least squares method, and Geiger's method (iterative, although sometimes referred to as a mixed method) [8]. The Simplex and Geiger methods (modified) were used in the ESG Micro-seismic event location program (ESG was a Canadian corporation, and its products were used in related researching projects).

1.2.2. P-wave technique

In the technique of P-wave, assuming a known constant P-wave velocity exists, the differences between two sensors can be calculated in distance with respect to another sensor from the recorded arrival times, while the actual distance from the hypocenter remains unknown. Therefore, four unknowns variable quantities were to be solved for: x, y, z and t, representing the location of the events and the corresponding time occurred. In order to solve the four unknowns, four arrivals were required, adding another arrival time allows the resulting equations to be simplified; five sensors were needed at least. The technique's basic solving equation is the time-distance equation:

$$Di=v_p t_i$$

Where:

Di=[(x-xi)2+(y-yi)2+(z-zi)2] 1/2

Marking the closest sensor '0th sensor', the difference in distance and arrival time between the 0th and ith sensor can be defined as follows:

$$d_{oi}=v_p t_{oi} \qquad d_i=d_{oi}+v_p t_{oi}$$

Square the above equations, expand them for d_i, d_o and d_{oi} (d_0 was unknown) by subtracting the ith equation from the 0th equation to remove the x^2, y^2 and z^2 terms (i.e., linearizing the equation).

$$2(x_0-x_i)x+2(y_0-y_i)y+2(z_0-z_i)z=d_{0i}+x_0^2+y_0^2+z_0^2-d_i^2-x_i^2-y_i^2-z_i^2$$

As d_0 was actually of little interest, it can be removed from the equations by subtracting the first equation from all other equations, and can be written in matrix form as:

$$\begin{bmatrix} A_{12} & B_{12} & C_{12} \\ A_{13} & B_{13} & C_{13} \\ A_{14} & B_{14} & C_{14} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} H_{12} \\ H_{13} \\ H_{14} \end{bmatrix}$$

This reduces the initial five equations to three, with three unknowns. Uniqueness of the solution is heavily dependent on the geometry of the sensor array and the size of the errors associated with the data. As such, a unique solution is not always possible, for example, a planar array will always have at least two solutions, regardless of the number of employed sensors.

In order to monitor and prevent the illegal mining the design of the sensor array should avoid being a planar or in a line.

1.2.3. Geiger's method (developed)

The event location is numerically approached in an iterative process from an initial trial solution. For each iteration, a correction vector (Dx, Dy, Dz, Dt) was calculated, based on least squares, and added to the previous solution to form a new solution. The iterative approach continues until preset criteria were reached. The solution was derived from the time-distance equation:

$$\left[(x_i-x)^2+(y_i-y)^2+(z_i-z)^2\right]^{\frac{1}{2}}=v(t_i-t)$$

Where *x, y, z* -coordinates of trial solution, *t* -event occurrence time, x_i,y_i,z_i location of sensor *i*, t_i - arrival time at sensor *i*

If trial solution approaches true solution, the observed arrival time *t, it* can be expressed in terms of the trial solution as a Taylor series.

$$t_{0i} = t_{ci} + \frac{\partial t_i}{\partial x}\Delta x + \frac{\partial t_i}{\partial y}\Delta y + \frac{\partial t_i}{\partial z}\Delta z + \frac{\partial t_i}{\partial t}\Delta t$$

Where: t_{oi} observed arrival time at sensor *I*, $t_{ci:}$ calculated arrival time at sensor *I* and

$$\frac{\partial t_i}{\partial x} = \frac{(x_i - x)}{vR} \quad \frac{\partial t_i}{\partial y} = \frac{(y_i - y)}{vR} \quad \frac{\partial t_i}{\partial z} = \frac{(z_i - z)}{vR} \quad \frac{\partial t_i}{\partial t} = 1$$

$$R = \left[(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2 \right]^{\frac{1}{2}}$$

or in matrix form:

AΔx = B

Which was solved by gaussian elimination

ATAΔX=ATB

Or: $x = \left(A^T A\right)^{-1} A^T B$

The correction vector was added to the previous trial solution to form a new trial solution, with the process repeating until a given error criterion was fulfilled, for which the final trial solution was considered to be the true event location.

2. The function of Monitoring and preventing illegal mining

2.1. The function developing of MMS

The problem of resource been stolen puzzled many national mines in China. Most thieves are personal mine owners nearby, using inclined shafts arrival in the rich and thick ore mass of the national mine, excavate ore mass with predatory mining before the real owner reach the point[9].

The great attention had been thoroughly aroused to the harm of illegal mining, since it not only cause property infringement to country, but also to legal ore property right owner, even more seriously, it can destroy the natural resources, amplify the disaster accident potential, damage the economical environment, at the same time, it can also threat the life safety of the miner that participate in the illegal mining. Due to predatory mining executives of the illegal mining, the ore recovery ratio was very low and it cause serious damage of the ore reserves. It would decrease the service length of state-owned mine because the remnant ore reserves can not normal recover. Meanwhile, the unknown gap may produce during the illegal mining process, water inrush may occur if there exists water accumulation in the gap. Simultaneously, the pit of illegal mining has so much shortage such as: backward manufacturing techniques, simple and crude of equipment, without support, imperfect of air and drainage system, so it didn't have the elementary condition of safety production, short of safety awareness of miner, hidden trouble is great during the illegal mining process·

At present, no special equipment and method can record the accurate time and three-dimension of coordinate of the illegal mining ore blocks in first time. It can greatly enhance the level of geological disaster monitor of installing and using of micro-seismic monitoring system in mine. The function of guard against illegal mining was developed by the project team to satisfy the task of guard against of illegal mining.

2.2. Principle of preventing illegal mining system (micro-seismic monitoring system)

It can quickly fix the three-dimension position and provide the space-time parameters of ore block stolen in the fighting illegal mining action. It was mainly aim at the three-dimension location of real time for the monitoring of the illegal mining signal, therefore, it should specially collect the blasting signal when filtering waves and analyze separately. Meanwhile, it was easy to distinguish the blasting waves owing to the large blasting vibration signal energy, so it was apt to realize the location analysis in the micro-seismic monitoring system and the information often was accurate. The corresponding principle was shown as: (according to the micro-seismic events excited by the blasting during illegal mining,) the first arrival time of the compression wave and shear wave of seismic waves was the data source (was collected) which excited by the blasting during illegal mining in the monitoring technology. Then it was used to compute the location coordinate and time by corresponding mathematical algorithm, then revise the data computed by the geological model established by the mine, thereby to confirm the accurate location of illegal mining, so it can fundamentally improve the disadvantage monitoring condition of illegal mining [10-11].

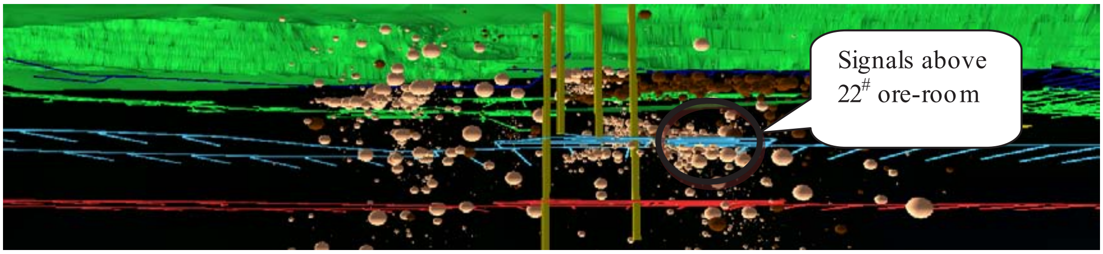
2.3. System composition of preventing illegal mining equipment

The technical proposal of the research was as follows: the sensors were distributed in the tunnel of doubting illegal mining, (it can install in the drilling hole of the tunnel wall, or paste on the tunnel wall through wireless sensor) the signal can transfer to the computer through signal gathering system, then the signal can be analyzed by special software system, the three-dimension location of blasting during illegal mining can be fixed. Meanwhile, the micro seismic events coverage area can analyzed to forcasting pressure disaster by analyzing the distribution condition of ground pressure.

2.4. A case of micro seismic monitoring system of guard against illegal mining

A set of MMS has been installed in an ire mine of Hebei province, and collected many signals which puzzled researchers much. Fig.1 shows the data during March of 2009, the analysis attention was paid on the strong seismic signal of 22# chamber. Since there was no normal production operation in this area, the signal shows the seismic events were on a standard of blasting events ranging wide with strong energy and the accumulate events were obvious. In view of above, the project team provides report that it was possible existing illegal mining action in some area (including the location of coordinate range) in the mine zone. Three-dimension track of illegal mining could not be caught well due to the system running time was short. Therefore, it could not provide serviceable information of illegal mining channel. The site of illegal mining was found when tunneling the patio of 22# experiment ore block, the location was coinciding with the monitor information. The severity degree was shown in a report of “report about the large area goaf existed in north district of 22# chamber”.

In the report, it said that a large mine goaf was found in 22# ore-room by technicians of mining workshop on Oct 14 afternoon, where hydraulic and electric power and high-pressure wind system were usable, and some drilling equipment and drainage pumps were left, the trails of scraper tire were clear. All of them showed that it was a goaf of illegal mining with a large scale and high degree of mechanization.



The events during 2009.3.1-31

Fig.1 signals above the 22# ore-room while there were no normal pproduction activities

3. Conclusions

The seismic monitoring technology was widely used in mine, petroleum and other fields; it proved to be powerful monitoring instrument on rupture failure and instability of rock. At the same time, by deep going study the system principle and location algorithm , it can not only be good for preferably design the sensors distribution to adapt all kinds of installation environment, but also in favor to develop the auxiliary function of system. It fully conforms to the strategic thought of new and high technology products of our country "introduction, digestion, integration, innovation, improve".

As the traditional optimization methods, the least square method, simplex method and Geiger algorithm, each has itself special requirements of algorithm; therefore, it should change the algorithm nature to develop its new function to get good new effect. This paper analyze the algorithm and its feasibility on seismic rescue and guard against illegal mining and develop and complete the auxiliary function.. A case of illegal mining and knocking test was studied to prove the function of rescue after disaster and guard against illegal mining. The seismic monitoring technology made certain contribution on its development and application not only on theory but also in practice.

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References

[1] Jiang Fuxing,Ye Genxi and Wang Cunwen. Application Of High-Precision Microseismic Monitoring Technique To Water Inrush Monitoring In Coal Mine[J]. Chinese Journal of Rock Mechanics and Engineering,2008,27(9):1932-1937.（in Chinese）

[2] Zhao Xing-Dong, Li Yuan-Hui and Liu Jian-Po. Study on Microseismic Activity in Potential Rockburst Zone During Deep Excavation in Hongtoushan Mine[J]. Journal of Northeastern University(Natural Science),2009,30(9):1330-1334. （in Chinese）

[3] Xu Nuwen, Tang Chun'An and Zhou Zhong. Identification Method Of Potential Failure Regions Of Rock Slope Using Microseismic Monitoring Technique[J]. Chinese Journal of Rock Mechanics and Engineering.2011,30(5):893-900. （in Chinese）

[4] A. Hirata, Y. Kameoka, T. Hirano. Safety Management Based on Detection of Possible Rock Bursts by AE Monitoring during Tunnel Excavation [J]. Rock Mechanics and Rock Engineering, 2007, 40(6): 563-576.

[5] Li Rui,Wu Aixiang,Wang Chunlai. Study on the Major Characteristics and Relationship of Microseismic Monitoring Parameters [J]. MINING R & D 2010, 30 (6) : 9- 11. （in Chinese）

[6] A. V. Gorbatikov, A. V. Kalinina, V. A. Volkov, J. Arnoso, R. Vieira, E. Velez. Results of Analysis of the Data of Microseismic Survey at Lanzarote Island, Canary, Spain [J]. Pure and Applied Geophysics, 2004,161 (7):345-363.

[7] Richard McCreary, John McGaughey, Yves Potvin, Dave Ecobichon, Marty Hudyma, Harald Kanduth, Alain Coulombe. Results from microseismic monitoring, conventional instrumentation, and tomography surveys in the creation and thinning of a burst-prone sill pillar [J]. Pure and Applied Geophysics PAGEOPH, 1992,13 (3-4):253-262 .

[8] Ur bancic T I, Trifu C I. Recent advances in seismicmonitoring technology at Canadan mines [J]. Journalof Applied Geophysics, 2000, (45): 225-237.

[9] Feng guolei. Mine Gravel Monitoring System Demonstration Studies [M].Jilin China:Jilin university, 2006 （in Chinese）

[10] Cichowicz A. Automatic processing and relocation methods[C] //Potvin Y, Hudyma M , ed. Controlling Seismic Risk ,Proc of the 6th International Symposium on Rockbursts and Seismicity in Mines. Nedlands: Australian Centre for Geomechanics, 2005:547 - 554.

[11] XU Nuwen,TANG Chunan,SHA Chun et al. Study on Microseismic Activity in Potential Rockburst Zone During Deep Excavation in Hongtoushan Mine [J]. Chinese Journal of Rock Mechanics and Engineering2009,30 (9): 1330- 1333. （in Chinese）