HAZARD MONITORING IN MINES USING FIBER OPTIC SENSORS

T. Liu, C. Wang, Y. Wei, Y. Zhao, Y. Shang
Laser Inst. Shandong Academy of Science, China

D. Huo, Z. Wang

Yanong Ning
Intelligent Sensor Systems Ltd. UK

OUTLINE

- Background - Mine Hazards
- FOS based Intelligent Mine Safety Monitoring Systems
  - Roof condition and water burst monitoring
  - Early fire detection
    - Power safety monitoring
    - Spontaneous fire early warning
  - Methane gas monitoring
  - Field trials: coal mines, tailings dam landslide
- Summary
CHINESE COAL MINE INDUSTRY

- Coal provides majority of the energy (>70%);
- Annual Production: ~3 billion tons,
- ~ 1/3 of world coal production;
- Number of coal mines: ~15,000
  - State and local government own ~3,000, the rests are small mines;
- Used to be >70,000 mines
- Key Issue: SAFETY
COAL MINE SAFETY

2001-2005:
- Number of coal mine accidents: 18,516
- Number of death: 31,064 (AVE: 17 per day !)
- In recent years, both the government and the mine operators invested heavily on safety technologies, the fatality rate dropped, but total number still very high.

FATALITIES DUE TO EXPLOSION:
- State owned mine groups have world class safety standard;
- However, in small mines casualty rate over 100 times higher.
MAJOR COAL MINE HAZARDS

2006 Jan-Oct: Fatalities

- **GAS OUTBURST**: 987
- **ROOF**: 1615
- **WATER**: 346
- **TRANSPORT**: 415
- **FIRE**: 75
- **FLOODING**: 346
- **Roof collapse, rock & coal outburst**: 1615
- **Methane explosion**: 75
- **BLASTERS**: 415
To develop a comprehensive mine disaster management system based on fiber optic sensor network, capable of mining hazard early warning and control.
Various mining hazards are interlinked, they do not happen alone;
Detectable symptoms exist prior to disasters happen.
ROOF COLLAPSE, ROCK BURST

Large area of roof sudden collapses,
thousands of tons of rock and coal burst out
casualties and struct damages.
Roof monitoring: roof displacement, seismic, not compulsory:

Resistance strain gauges, suffer drifts, often off line...
Rock Strain, Roof Displacement Sensors

- FBG rock strain sensor array on steel bar
- FBG array
- FBG roof displacement sensor,
- d transferred to FBG strain
Sensors for Water Burst Detection

- FBG Pressure sensor with built-in temperature sensor;
- For mineral mine safety application, where major hazards are water flooding, tailing dam, and roof fall.
**Multi-Parameter FBG Sensor Sys.**

- FBG-based $T$, $P$, water level, $\varepsilon$, $d$ sensor multiplexing system,
- WDM & Spatial multiplexing, up to 100 fiber channels,
- Address $>1,000$ sensors per system;
- Mine safety certified (MA);
- with internet access and TXT message auto-warning.
Cantilever based accelerometer:
Acceleration results in mass displacement, then FBG strain variation.
**Micro-Seismic Sensor Interrogation**

1. Saw-tooth laser current sweep to locate FBG reflect. Spectrum

![Diagram of Micro-Seismic Sensor Interrogation](image)

2. SCM PID control to lock the DFB LD to -3dB point in the FBG spectrum.
Micro-Seismic Sensor Interrogation

- FBG edge to give acceleration signal;
- PID LD current lock to track FBG slow drift.
Micro-Seismic Sensor Character.

- Sensitivity: 0.1mg;
- Range: 0-10g.
- BW: 3-400 Hz
- Auto-drift compensation
COAL MINE FIRE

n 2008.09 Hegang Spontaneous coal fire causing 19 people died;

n 2007.02 Henan Province, 17 died in a power cable joint overheat caused fire.
**Mining Power Station Condition Monitoring**

- **Internet server**
- **FBG Interrogator**
- **Fiber connection**
- **Optical fiber cable**
- **On-line high voltage switchgear temperature monitoring**
- **FBG Temperature sensor**
Fire Prediction and Location

- 6-10 km range

- Raman DTS
- T Monitor and fire warning
- Location system

armoured cable for underground mined-out area;
along power cable.
Underground spontaneous coal fire can occur as soon as 14 days after production; Early detection can be made by monitoring CO (@1567nm), CH$_4$ (@1665nm) and C$_2$H$_4$ (@1630nm); O$_2$ (@762nm);

Ratio of CO/O$_2$, C$_2$H$_4$/C$_2$H$_6$ are useful indicators;

Require ppm sensitivity and accuracy;
Multi-Gas Trace Detection System

- Multiple reflection to enhance the detection sensitivity;
- 2nd harmonic detection and PLIA to reduce noise;
- ~ 1 ppm sensitivity for CO, sub-ppm for C₂H₄, C₂H₆;
One gas cell addressed by a bank of laser diodes, which emits at an absorption band of the gases to be monitored.
Multi-Gas Detection System

\[ y = 0.0033x - 0.0043 \]
\[ R^2 = 0.9988 \]

C\textsubscript{2}H\textsubscript{2} concentration vs \( V_{2f}/V_{1f} \).

Illustration how the harmonic detection system work.
Over 50% underground coal mines in the world are gassy;
METHANE EXPLOSION

- **2001.11, Shanxi Datong, Explosion, 54 people died;** Operation to suppress poisonous gases emitted.

- **2006.11 Jiangxi explosion, 7 people died.**

- **2001, Shanxi, explosion 99 people died**
Seismic Trigger Methane Gas Burst

Seismic Event 17:17

Gas outburst in ~40 minutes

From Geo-Physics Vol. 19, p 856
FO Methane Gas Sensor

- Ambient Gas Sensor
- Pipeline gas sensor

Sensor consists of pairs of fiber collimators as gas cell;
Fixing Support and anti-vibration mechanism;
Dust and moisture filters
FO Methane Detection Principle

Laser sweep with internal referencing to achieve field stability.
**FOS Methane Monitor**

- **Unique benefits:**
  - Long calibration cycle;
  - Immune to gas cross talk;
  - Robust to humidity and ambient T
  - Intrinsically safe

\[ y = 1.0025x + 0.0526 \]
Coal Bed Methane Utilization Monitoring - Latest Field Trial

Huainan Coal Mine methane power generation plant 2009.09

Data points (once/half hours in two days)

- Fiber gas sensor (MS-GXM-01)
- Traditional sensor 1
- Traditional on-line sensor
Coal Mine Methane Utilization Monitoring

(Methane extraction power generation plant, Fuxin, Liaoning, 07. 2008)
Intelligent Mine Safety Platform

- All fiber optic multi-parameter sensor network, comprising 3 sub-systems:
  - Multiplexed FBG sensor array (d, P, T, ε, a, flow, AE)
  - Laser absorption based gas sensor array (Ch4, CO, C2H4, CO2, O2)
  - DTS
- Data fusion system
Field Trial:
LINGZI COAL MINE, SHANDONG

- Temperature
- Seismic
- Strain
- Methane

The first trial in 2007
FIELD INSTALLATION

Illustration of Fiber Optic Sensor Installation in the Mine.
Illustration of water pressure measurement using fiber optic pressure sensors.
Fiber Optic temperature sensors and methane sensors installed in underground coal mine.
Underground temperature is recorded at approximately 22 degree C, accurate within +/-0.5 degree.
Record of methane gas concentration change with time (increase of concentration can be observed after blaster events which agrees with the conventional sensor data).
Laiwu Iron Ore Mine Roof Monitoring

Fiber load cell

Displacement sensor
Recorded mining blaster signals by two FO seismic sensors located 170 m apart. The time delay is apparent which can be used for seismic source location.
The FOS mining safety information system is for on-line remote access via internet.
Internet access
Tailings Dam Condition Monitoring

Mineral mine hazards mainly concerned with underground roof and ground tailings dam safety monitoring.

Fiber optic water level and displacement sensor network are developed.

Illustration of an iron ore mine tailings dam monitoring system in Beijing, 06.2008.
Field Trial: Methane Sensor UK Waste Process Power Plant

Global secure remote methane monitoring and Data Access

On-going field trial in the UK 09.2009.
Field Trial: Methane Sensor UK Waste Process Power Plant

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On Going Work – Comparative Study With PZT Seismic Sensor Network

Real PZT Seismic recording
And location.
To put OFS in the same Location as the PZT and compare sensors
Challenges and Opportunities

- OFS can play a key role in enhancing even revolutionizing coal mine and mineral mine safety;

- Fiber optic FBG sensors, DTS, laser spectroscopic gas sensors, seismic sensors have been successfully demonstrated to become a comprehensive mining safety and hazard management info system ... 

- The diversified, on-line, multi-location information provides a foundation for more accurate and timely mining hazard early warning and control;
**Challenges and Opportunities**

- OFS intrinsically safe in explosive environment, is irreplaceable for the development of modern intrinsic safe and digital mining.

- OFS also play key role in environmental system such as coal bed methane utilization...

- Many opportunities and challenges for OFS application in the mines, e.g. sensitive fiber microphone array for emergency rescue communication; dust monitoring; cable and sensor protection, etc.
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Welcome your collaboration!
Together, OFS can save lives and the planet!

Thank you for your attention!