2027 CCTEG-Funding Research Project (CFRP) Priorities

CCTEG

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01 Self-Powered Wireless Sensors for Mining

1. Urgency

Implementation within 1-2 years

2. Background and application context

As intelligent coal-mine development advances, underground wireless sensor networks are expanding rapidly to reduce cabling. They cover strata-pressure, gas, dust and equipment-condition monitoring. However, mining intrinsic-safety certification strictly limits battery capacity and type. Existing sensors generally use small intrinsically safe batteries lasting only 3-6 months, far short of the monitoring required throughout an equipment life cycle, typically 3-5 years.

Battery capacity is constrained by safety certification. Intrinsically safe mining equipment faces strict rules on battery capacity, chemistry and short-circuit current. Usually only small lithium-thionyl chloride or lithium-manganese dioxide batteries are permitted, so endurance cannot simply be extended by increasing battery capacity.

Underground battery replacement is costly and risky. Sensors are often installed on mobile or dispersed equipment such as shearers, armoured face conveyors and powered supports. Replacement requires production stoppages, some locations are difficult to access, and frequent enclosure opening may compromise flameproof or intrinsic-safety performance.

Existing energy-harvesting technologies are insufficiently adaptable. Light is virtually unavailable underground. Thermal-gradient energy depends on installation close to major heat sources. Vibration is abundant and widely available, but current piezoelectric and electromagnetic harvesters have low efficiency under low-frequency, broadband and variable operating conditions and cannot yet provide reliable self-powered operation.

3. Research requirements

3.1 Core problems and research scope

1. Intrinsic-safety compliance and low-power co-design: develop a self-powered architecture compliant with mining safety certification. Define intrinsic-safety matching conditions between the harvesting module, storage unit and sensor load, so that the complete system can obtain certification.

2. Ultra-low-power sensor nodes: investigate intermittent sampling, adaptive sleep and event-triggered wake-up. Reduce average power below the milliwatt level and match it to the output available from the energy harvester.

3. Energy-storage optimisation: investigate hybrid supercapacitor and micro-lithium-battery storage for underground self-powered systems, balancing instantaneous power delivery with long-term energy reserves.

4. Broadband vibration harvesting: optimise structures and broaden the operating bandwidth of piezoelectric, electromagnetic, triboelectric and hybrid harvesters for the low-frequency (10-200 Hz), broadband and variable-amplitude vibration of shearers and armoured face conveyors.

5. Thermoelectric module integration: develop attachment processes and thermal-management solutions for flexible thermoelectric modules at equipment locations with stable temperature

differences. Address curved-surface installation and long-term reliability.

6. Electromagnetic induction harvesting: investigate current-transformer-based contactless harvesting from electromagnetic fields around underground cables and motors, including cable-screen circulating currents or busbar currents.

7. Multi-source energy management and power aggregation: investigate impedance matching, power combination and intelligent switching between harvesting modules to maximise energy utilisation.

3.2 Expected outcomes and technical targets

1. Vibration-harvesting module output power density ≥1 mW/cm³.

2. Thermoelectric module output power ≥5 mW.

3. Electromagnetic-harvesting module output power ≥10 mW.

4. Continuous battery-free operation of a demonstration sensor node for ≥12 months.

4. Preferred cooperation modes

Joint research and development; Commissioned development; Technology transfer/licensing.

02 Wireless Communications and Networking at the Coalface

1. Urgency

Implementation within 1-2 years

2. Background and application context

The coalface is a complex environment. Current WiFi/4G/5G communications do not provide sufficient stability. Large, densely installed mining machines obstruct signals, causing rapid attenuation and blind spots at development headings and behind equipment. Conventional wireless systems struggle to provide uninterrupted coverage.

High-power roadheaders, shearers and other equipment generate strong electromagnetic interference, resulting in stalling and packet loss. Dust, humidity, vibration and flammable/explosive gases also impose demanding explosion-protection and ingress-protection requirements, including IP67 or higher.

As mining advances, the coalface moves continuously. Fixed communication nodes need frequent repositioning, and traditional network architectures cannot adapt rapidly. Remote shearer control and safety interlocking require very low latency and effectively loss-free transmission, while conventional solutions struggle to combine high bandwidth, low latency and high reliability.

3. Research requirements

3.1 Core problems and research scope

1. Complex-channel adaptation: address severe attenuation and multipath caused by narrow roadways and equipment obstruction, achieving continuous coverage without blind spots.

2. Strong-interference suppression: overcome non-Gaussian impulsive interference generated by high-power mining equipment, ensuring low packet loss and stable transmission.

3. Intrinsic-safety compliance: satisfy demanding underground explosion-protection, dust and moisture requirements and mining safety certification.

4. High-concurrency service support: enable simultaneous access by hundreds of sensors, control terminals and cameras, with smooth parallel transmission of multiple services.

5. Dynamic-scenario adaptation: accommodate continuous face advance, seamless terminal roaming and uninterrupted emergency communications during disasters.

3.2 Expected outcomes and technical targets

1. Deliver a wireless networking and deployment scheme tailored to the coalface, directly supporting remote shearer operation, 4K video uplink and precise personnel positioning.

4. Preferred cooperation modes

Joint research and development; Commissioned development.

03 Digital Geomechanical Characterisation and Intelligent Classification

1. Urgency

Implementation within 1-2 years

2. Background and application context

With increasing mining depth and intensity, digital characterisation of surrounding-rock structures, intelligent classification and mining-induced stress assessment under complex conditions have become key constraints on intelligent support design and scientific ground-pressure management. Phase I of this project has already produced a surface-version controllable impact-source prototype and completed field sonic-logging trials. It has a foundation in detection-equipment data acquisition and accumulated field datasets, together with geophysical equipment, rock-mechanics expertise and testing hardware. Internal AI R&D capacity is limited, so collaboration with partners with strong AI capabilities is required.

First, coal mines are noisy industrial environments. The project produces heterogeneous multimodal data: seismic waveforms, sonic logs, rock images, ground-pressure monitoring time series and borehole geological text. Formats differ, noise is strong, data are often missing and samples are imbalanced. Traditional processing struggles with efficient cleaning, feature alignment and intelligent imputation. Engineering automatic extraction of high-dimensional waveform and borehole-image features is difficult, limiting the quality of the heterogeneous geomechanical database.

Second, a large multimodal geomechanical model is technically challenging. Rock-mechanics prior knowledge must be integrated with deep learning using physics-informed neural networks (PINNs), Transformers and graph neural networks (GNNs), preserving both predictive accuracy and physical interpretability rather than creating a purely data-driven black box. Internal experience is limited in multimodal large-model architecture and implementation of embedded physical constraints.

Third, generalisation and engineering adaptation are difficult because geology varies greatly between mines. Efficient transfer learning and incremental online updates are needed to adapt a trained model to different mining areas and faces while reducing dependence on labelled data. Intelligent rock classification, semantic segmentation of rock structures, and fracture/weak-interlayer recognition also require hyperparameter optimisation and robustness validation for underground field use.

Fourth, lightweight AI inference for underground edge deployment is lacking. Existing vision-based rock-recognition and seismic-source interpretation models are large and cannot readily run on underground edge devices. Pruning and quantisation are needed to enable rapid local inference while maintaining accuracy and supporting real-time rock-structure characterisation.

These AI limitations constrain database quality and development of a geomechanical model with tens of millions of parameters. Relying solely on the existing team would prolong algorithm iteration and complicate deployment. Collaboration in AI, deep learning, multimodal large models, transfer learning and edge AI is sought to accelerate the project and support intelligent rock classification and support decisions in deep coal mines.

3. Research requirements

3.1 Core problems and research scope

1. The project already has a foundation in detection hardware, coal/rock-mechanics testing and geological data acquisition. This collaboration focuses on AI algorithms.

2. Intelligent preprocessing of heterogeneous geomechanical data: develop cleaning, anomaly removal, missing-sample imputation and cross-modal feature-alignment algorithms for impact-source seismic waveforms, sonic logs, machine-vision rock images, pressure time series and borehole records. Address strong noise, sample imbalance and modal differences to provide high-quality standardised datasets.

3. Physics-informed multimodal large-model architecture: establish a Transformer/GNN-based fusion framework and implement PINNs within deep-learning networks. Integrate constitutive laws and strength criteria during training to improve physical interpretability and avoid predictions inconsistent with geomechanics. Support a geomechanical model with tens of millions of parameters.

4. Transfer learning and incremental online updating: develop cross-mining-area adaptation with fewer labelled samples and enable online model iteration as new monitoring data arrive. Address geological differences and evolving conditions. Optimise semantic segmentation, fracture/weak-layer recognition and rock grading, including hyperparameter tuning and robustness validation.

5. Lightweight models and underground edge inference: prune and quantise image-recognition and geomechanical-prediction models, controlling accuracy loss and adapting them to underground edge devices for real-time characterisation of rock structures and geological parameters.

3.2 Expected outcomes and technical targets

1. A preprocessing algorithm toolkit supporting automated processing of seismic waveforms, logs, images and monitoring time series, producing standardised data directly compatible with the project database.

2. A multimodal large-model algorithm framework incorporating rock-mechanics constraints and supporting a model with tens of millions of parameters. It must classify surrounding rock and extrapolate geomechanical predictions in accordance with physical laws and with physical interpretability.

3. Transfer- and incremental-learning modules adaptable to complex geology across mining areas, with online updates using new field data without retraining on all samples. Complete semantic-segmentation and rock-classification optimisation and robustness validation.

4. Lightweight AI models for underground edge devices, enabling local rock recognition and geological prediction at the speed required for real-time field characterisation.

5. Algorithm source code and technical reports, support for model testing/validation, and assistance with SCI/EI papers and software copyright outputs in line with overall project objectives.

4. Preferred cooperation modes

Joint research and development.

04 Active Perception and Adaptive Grasping in Low Light

1. Urgency

Implementation within 1-2 years

2. Background and application context

Underground operations combine poor lighting, heavy dust and mist, confined spaces and randomly stacked rigid/flexible materials, including bolts, mesh, pipes, cables and bulk materials. Conventional visible-light vision fails under low light and grasping strategies cannot adapt adequately. These are common barriers to replacing manual work in loading/unloading, material handling, spare-parts picking and bulk-material removal. Machine vision, 3D point-cloud semantic segmentation and reconstruction are already available, but active target exploration and adaptive robotic-arm grasping under underground low-light conditions are lacking.

3. Research requirements

3.1 Core problems and research scope

1. Active-perception mechanisms: fuse multimodal sensors to autonomously explore and perceive targets within a local area under low light and other complex conditions, and estimate the 6D pose of specific targets.

2. Adaptive grasping: develop robotic-control algorithms for randomly stacked, mixed rigid/flexible materials under limited sensing conditions.

3.2 Expected outcomes and technical targets

1. Deliver one adaptive robotic material-handling and grasping system. Achieve a grasp success rate above 90% for materials such as roof bolts, drill rods and anchoring agents in roadway-development scenarios.

4. Preferred cooperation modes

Joint research and development.

05 Self-Propelled Borehole Robot for Coal–Rock Interface Sensing

1. Urgency

Implementation in 3-5 years

2. Background and application context

Transparent geology and intelligent mining require finer identification of roof/floor interfaces, partings and local anomalies. Existing boreholes usually depend on one-off probing and do not provide enough continuous high-resolution information. Small diameters, irregular walls, water, coal slurry and local collapse restrict conventional probe access, positioning and safe recovery. Borehole radar has demonstrated that coal-rock interfaces can be detected along in-seam holes, but borehole geometry, roadways and metal supports cause interference. Autonomous mobility therefore needs to be integrated closely with multi-source geological sensing.

3. Research requirements

3.1 Core problems and research scope

1. Develop adaptive locomotion/anchoring and autonomous recovery mechanisms for small-diameter holes, enabling stable outward and return travel despite changing diameter, bends, wet/slippery surfaces and local obstacles. Integrate borehole vision, acoustic/ultrasonic, electromagnetic or resistivity sensors and develop fusion-based recognition of coal-rock interfaces, partings and anomalies. Address GPS-denied joint odometry/attitude positioning, communications, power supply and motion control, achieving accurate spatial registration of sensing results to borehole trajectories.

3.2 Expected outcomes and technical targets

1. Deliver a proof-of-concept robot and control software, validated in experimental boreholes and coal mines. Enable autonomous return travel, status monitoring, fault protection, safe recovery and continuous geological data acquisition. Develop interface-recognition and trajectory-registration algorithms. Output interface positions and anomalies suitable for updating transparent geological models, and establish reusable mechanical design, sensor integration, control and field-test methods.

4. Preferred cooperation modes

Joint research and development.

06 Optimisation and Simulation of Time/Frequency-Domain EM Antennas

1. Urgency

Implementation in 3-5 years

2. Background and application context

Underground time/frequency-domain electromagnetic exploration requires broadband response, appropriate transient characteristics and interference resistance. Antenna performance directly affects early-time signal quality, resolution and effective detection range. Coil/antenna size, bandwidth and quality factor are mutually constrained. Residual response after turn-off, ringing and amplitude/phase distortion can mask weak anomalies, while metal supports and complex media alter field distributions and coupling. City University of Hong Kong has relevant expertise in broadband, reconfigurable/metasurface antennas and multi-objective optimisation, supporting joint development under complex constraints.

3. Research requirements

3.1 Core problems and research scope

1. Establish integrated full-wave/circuit co-simulation for underground time- and frequency-domain exploration. Analyse antenna geometry, materials, shielding, matching networks, transmitter-receiver spacing and the metal environment. Optimise transmit field strength, turn-off time and low ringing, together with receive sensitivity, bandwidth, noise and dynamic range, improving useful signal acquisition in early-time windows. Investigate multi-objective and machine-learning-assisted optimisation across size, power, bandwidth, efficiency, directivity and time-domain fidelity, and establish a simulation-prototype-calibration loop.

3.2 Expected outcomes and technical targets

1. Deliver a parametric simulation and optimisation platform with key structural, matching and shielding designs. Produce high-performance transmit/receive prototypes and laboratory calibration, including frequency/transient response, sensitivity and interference-resistance curves. Develop response-compensation and calibration algorithms and reusable design rules, optimisation algorithms and test/evaluation methods for antenna families across underground exploration scenarios.

4. Preferred cooperation modes

Joint research and development.

07 Multimodal Coal–Rock Interface Sensing for Intelligent Extraction

1. Urgency

Implementation within 1-2 years

2. Background and application context

Intelligent extraction requires shearers to identify coal, rock, partings and roof/floor interfaces in real time, providing a basis for adaptive drum-height, haulage-speed and cutting-parameter control. Dust, low illumination, sprays and strong vibration undermine single vision/load signals, and significant domain differences exist between seams and machines. Research indicates that images/laser point clouds, vibration/current and active infrared sensing can improve recognition, but continuous field identification, cross-mine generalisation and closed-loop connection to control systems still require development.

3. Research requirements

3.1 Core problems and research scope

1. Develop multimodal sensing robust to heavy dust, low light and sprays. Fuse visible/infrared imagery, laser point clouds, vibration, current and acoustic data to jointly identify coal/rock classes and interfaces. Build datasets covering coal types, surrounding rock, cutting states and machine conditions. Investigate few-shot learning, transfer learning and domain adaptation to improve generalisation across mines/faces. Develop multi-source spatial/temporal synchronisation, online fusion and lightweight real-time inference, linking recognition to shearer pose, drum height and haulage-control parameters.

3.2 Expected outcomes and technical targets

1. Deliver a prototype system including the sensor combination, acquisition, recognition algorithms and visualisation software. Establish a representative multimodal dataset and evaluation framework. Output coal/rock class, interface position and confidence in real time and support rapid model transfer/updating. Provide control-system data interfaces and application schemes supporting automatic drum-height adjustment, intelligent cutting and reduced-personnel extraction.

4. Preferred cooperation modes

Joint research and development.

08 Bidirectional Digital Twins of Geology and Mining/Drilling Equipment

1. Urgency

Implementation within 1-2 years

2. Background and application context

Geological models used during extraction, development and drilling are usually built from earlier exploration. While-drilling data, equipment poses, loads and online sensing are not incorporated promptly, so models gradually diverge from field conditions. Geological information often remains a visualisation/query aid rather than a real-time basis for equipment path planning, parameter optimisation and risk warnings. Digital twins require bidirectional physical-virtual synchronisation and feedback, but heterogeneous data, inconsistent spatial/temporal references, real-time updating and uncertainty representation remain barriers.

3. Research requirements

3.1 Core problems and research scope

1. Establish common spatial/temporal coordinates and semantic models for geology, mining equipment and drilling equipment, connecting drilling parameters, trajectories, geophysics, poses, cutting loads and equipment states. Develop dynamic updating using geological rules, physical models and data-driven algorithms. Assimilate new while-drilling/while-mining information into 3D geological models in real time and quantify uncertainty. Develop reverse services from geology to equipment for paths, cutting/drilling parameters, anomaly warnings and recommended control strategies, with prediction, simulation and closed-loop correction in digital space.

3.2 Expected outcomes and technical targets

1. Deliver the architecture, data standards and prototype platform for bidirectional geological/equipment twins, including real-time data access, equipment-state mapping and dynamic geological updating. Demonstrate physical-virtual synchronisation in representative mining or drilling settings. Provide core modules for model updates, data assimilation, equipment-behaviour prediction and closed-loop optimisation. Validate in field or hardware-in-the-loop conditions and produce a replicable technical route and modular interfaces for coordinated transparent geology and intelligent equipment control.

4. Preferred cooperation modes

Joint research and development.

09 High-Value Utilisation of Solid Waste

1. Urgency

Urgent implementation within six months; also selected as a long-term development priority

2. Background and application context

China is at a transition from treating coal-derived solid waste as a disposal burden to creating resource value. Coal-gangue stockpiles exceed 7 billion tonnes. Traditional building-material outlets are narrowing as construction demand slows, driving higher-value functional applications. Ecological utilisation is strategically valuable: gangue contains silicon, aluminium, iron and calcium and can improve soil structure and mineral nutrients, combining local waste use with ecological improvement.

Arid mining environments create major constraints: extremely poor soils, low rainfall, drought and weak soil structure impose multiple interacting stresses. Existing treatments often improve a single indicator without first diagnosing limiting factors. Formulations effective in the laboratory may fail in the field under drought stress.

Research indicates that combined arbuscular mycorrhizal fungi and functional bacteria can improve rhizosphere nutrient levels and plant stress tolerance. Practice at Wuhai Energy and elsewhere also indicates that microbially transformed gangue can support restoration in arid mining areas with little or even no irrigation. Coal-derived waste can serve as a microbial carrier, water-regulation medium and slow-release mineral-nutrient source within a plant-microbe-soil network, rather than only as filler or a chemical amendment. Modification therefore needs to combine water regulation, slow nutrient release, microbial support and root development.

High-value utilisation technologies are urgently needed that link constraint diagnosis, customised materials, biological matching and system coordination to soil improvement and ecological reconstruction.

3. Research requirements

3.1 Core problems and research scope

1. Characterise carbon fractions, mineral composition and pore structure in gangue, fly ash and gasification slag. Identify how components affect nutrient supply, water/salt regulation, structure and biological activity. Investigate activation, release and transformation in arid/saline soils. Relate occurrence forms and release behaviour to soil-function responses, identifying dominant functional components and suitable operating ranges.

2. Develop carbon/nutrient activation and surface-functional-group regulation using thermal activation and microbial decomposition, producing porous biochar and highly active humic-acid base materials. Combine organic/inorganic functional materials and attached functional microbes for soil improvement and fertility. Develop root-zone water-retention and leaf-transpiration-suppression materials through stronger water retention and stomatal regulation, and establish composition-performance relationships for drought resistance.

3. Establish full-chain carbon-footprint accounting from collection and pretreatment to manufacture and engineering application. Quantify emission reductions from replacing conventional soil amendments, water-retention agents and fertilisers. Build carbon-sink benefit models and compare pathways including soil improvement, water retention and ecological restoration. Establish an industry carbon-footprint database to support technology selection and policy with quantitative evidence.

3.2 Expected outcomes and technical targets

1. Coal-derived solid waste content in soil-improvement/drought-resistance materials ≥70%.

2. Restored-soil organic matter >35% higher than surrounding mining-area soils.

3. One formulation-design method for synergistic utilisation of coal-derived solid wastes.

4. Preferred cooperation modes

Joint research and development; Commissioned development; Joint laboratory/cooperation base; Researcher exchange/training.

10 5G/6G Wireless Communications and Networking

1. Urgency

Implementation within 1-2 years

2. Background and application context

Underground 5G already supports HD video uplink, voice dispatch, equipment control and personnel positioning. However, long narrow roadways, bends, dense metal equipment, obstruction and multipath cause rapid attenuation at long range, around bends and without line of sight, limiting continuous coverage and link stability. Large numbers of video streams, inspection robots and vehicle terminals increase uplink/concurrency demand. Handovers between base stations can cause delay, packet loss and interruptions.

High 5G base-station power consumption conflicts with intrinsic-safety/explosion-protection requirements and limited underground power-supply capacity. Short single-station coverage also increases base stations, fibre and power infrastructure, raising construction and maintenance costs. Longer coverage, stable links, higher uplink bandwidth, lower power and smoother mobility remain central issues for large-scale underground adoption.

3. Research requirements

3.1 Core problems and research scope

1. Complex-space coverage: narrow roadways, bends, junctions, metal supports, vehicles and large machines cause reflection, diffraction, multipath and non-line-of-sight propagation. High-frequency 5G attenuates particularly strongly after bends/obstruction, often providing good straight-roadway coverage but rapid deterioration at bends and the face, requiring denser base-station deployment.

2. Range-bandwidth trade-off: reduce base-station numbers and extend range while supporting HD video, equipment data and control. Modulation/coding levels fall with distance, reducing effective bandwidth and making long range, high bandwidth and low latency difficult to achieve together.

3. Power and intrinsic safety: RF amplifiers, baseband processing and switches consume more power than traditional mine wireless equipment, whereas intrinsically safe supplies strictly limit output, stored energy and transients. Study multiple intrinsically safe supplies, separated power domains, staged startup, dynamic power management and RF optimisation.

4. Multi-system integration: 5G, 4G, WiFi, UWB, dispatch communications, broadcasts, positioning and industrial Ethernet coexist underground. Incompatible numbering, authentication, location data, audio/video and dispatch interfaces create communication silos. Integrate 5G with WiFi, UWB, dispatch telephones and video systems.

5. Cost and rapid deployment: limited coverage increases base stations, fibre, supplies, explosion-protected equipment and maintenance points. Advancing headings require repeated extension and adjustment. Reduce wired backhaul, extend single-station coverage and enable fast deployment.

3.2 Expected outcomes and technical targets

1. Validate the underground applicability of 5G/6G communications and networking technologies and develop supporting prototypes.

4. Preferred cooperation modes

Joint research and development; Commissioned development.

11 Underground Dust Monitoring and Personal Cooling

1. Urgency

Implementation within 1-2 years

2. Background and application context

Underground faces combine high dust, humidity and temperature. Existing dust monitors are affected by fouling and moisture, with signal drift and frequent false alarms, preventing stable long-term online monitoring. Heat stress is severe. Effective cooling may be unavailable or depend on energy-intensive large refrigeration equipment, and lightweight personal-cooling technologies are lacking.

Conventional dust and temperature monitors have been deployed, but interference resistance and environmental adaptation under heavy dust remain inadequate, as do passive personal-cooling materials. Frontier university technologies from Hong Kong are sought for adaptation to underground conditions, improving dust-monitor reliability and thermal comfort.

3. Research requirements

3.1 Core problems and research scope

1. Stable dust monitoring: draw on Hong Kong Polytechnic University work in spectral sensing under heavy dust and memristor neuromorphic signal processing. Jointly develop underground terminals, addressing signal drift, fouling interference and false alarms in high dust/humidity. Investigate dust-resistant optical structures and interference-cancellation algorithms for stable online measurement.

2. Passive personal cooling: adapt University of Hong Kong passive radiative-cooling metamaterials to enclosed underground conditions. Develop flexible protective cooling fabrics and vest prototypes for miners, providing passive cooling against heat stress. Also investigate applications in local underground work chambers.

3.2 Expected outcomes and technical targets

1. An interference-resistant dust-monitor prototype for 200-800 mg/m³ dust and high humidity, suppressing fouling/moisture drift, interfacing with existing mine monitoring/communications and ready for pilot deployment.

2. Passive personal-cooling fabrics and vest samples suitable for underground wear and effective personal cooling, together with a report on radiative-cooling material modification for underground conditions.

3. Complete technical reports, prototypes/samples and laboratory performance tests, providing a basis for subsequent intrinsic-safety/explosion-protection adaptation and underground trials.

4. Preferred cooperation modes

Joint research and development; Commissioned development; Researcher exchange/training.

12 Neuromorphic Sensing of Underground Gas Mixtures

1. Urgency

Implementation within 1-2 years

2. Background and application context

Coal mines are harsh industrial and highly hazardous explosive environments. Faces, return airways and goafs commonly combine 25-40°C, 70%-95% RH, 200-800 mg/m³ coal dust and mixed gases including CH_4, CO, CO_2 and O_2. Conventional electrochemical mine sensors face three problems: strong cross-sensitivity, with CO particularly affected by reducing gases such as H_2; temperature/humidity drift, unstable zero baselines and repeated shutdown calibration; and limited intelligence for automatic calibration and real-time feedback.

The existing KJ3093 mine-gas patrol system uses laser methane and infrared CO_2 sensing, improving some accuracy issues. Bottlenecks remain in one-step identification of multi-component mixtures, long-term stability under humidity/fouling and millisecond parallel response. Frontier micro/nanosensing and memristor neuromorphic technologies from Hong Kong universities are sought to overcome poor environmental adaptation, selectivity and intelligence.

3. Research requirements

3.1 Core problems and research scope

1. Highly selective simultaneous recognition: develop differentiated sensing pixels using gradient nanofilm arrays so CO, CH_4, CO_2 and O_2 generate non-overlapping characteristic electrical signals. The proposed WO_3/ZnO/CuO/TiO_2 gradient-nanofilm plus memristor-neuromorphic route aims to fully separate four channels and overcome frequent false alarms.

2. Adaptive interference rejection: develop a two-layer memristor computing array. The first layer filters dust/humidity interference, and the second identifies gas type and concentration. Detection-accuracy degradation must be ≤2.2% over three months of continuous operation without production stoppages or dismantling for calibration.

3. Millisecond response and low-power intrinsic safety: develop an optoelectronic memristor sensing module to improve the currently excessive T_{90} response time and support second-scale warnings of sudden gas release. Target response ≤2 ms and average static system power ≤10 mW, meeting GB 3836.4 Ex ia I Ma, the highest intrinsic-safety protection level specified in the source.

3.2 Expected outcomes and technical targets

1. The optoelectronic memristor module must selectively monitor major underground hazardous gases and environmental safety indicators. The required detection purposes, ranges and error limits are listed in the table below.

Gas	Monitoring purpose	Measurement range	Detection error
Methane (CH_4)	Explosion safety and gas-outburst monitoring; ventilation/gas-drainage monitoring	Routine safety: 0.00-4.00% vol High-concentration drainage: 0.00-100.0% vol	0.00-1.00%: ±0.05% 1.00-100%: ±5% of true value
Carbon monoxide (CO)	Early warning of coal spontaneous combustion; underground toxic-gas safety limits	0-1000 ppm	0-100 ppm: ±4 ppm >100-500 ppm: ±5% of true value >500-1000 ppm: ±6% of true value
Oxygen (O_2)	Prevention of oxygen-deficiency asphyxiation; safe working conditions	0.0-25.0% vol	±0.5% vol
Carbon dioxide (CO_2)	Ventilation assessment; gas-release monitoring in goafs and sealed areas	0.00-5.00% vol	0.00-0.50% vol: ±0.10% vol 0.50-5.00% vol: ±(0.05 + 5% of true value)
Hydrogen sulphide (H_2S)	Prevention of acute inhalation poisoning by a highly toxic gas	0-100 ppm	0-100 ppm: absolute error ±5 ppm ≥100-200 ppm: ±5% of true value

4. Preferred cooperation modes

Joint research and development; Commissioned development; Researcher exchange/training.

13 Neuromorphic Continuous Monitoring of Hazardous Coalfield-Fire Gases

1. Urgency

Implementation within 1-2 years; also selected as a long-term development priority

2. Background and application context

Coalfield-fire control is an international research focus and a major unresolved challenge. Coalfield fires involve uncontrolled incomplete combustion, emitting sulphur dioxide, nitrogen oxides, carbon monoxide and strong carcinogens, as well as large quantities of carbon dioxide and methane that aggravate climate change. Conventional gas monitoring has poor long-term sensor stability and temperature/humidity tolerance, together with response delays that do not meet environmental monitoring needs. The team has developed laser online gas monitoring, coalfield-fire gas-monitoring technologies and a multi-source-data warning platform.

Recent breakthroughs in memristor neuromorphic computing offer opportunities in gas sensing. Multi-component gradient-nanofilm sensing chips provide perception, while memristor computing provides cognition, integrating sensing, memory and computation in hardware. This may fundamentally address false alarms and slow responses.

3. Research requirements

3.1 Core problems and research scope

1. Develop compact, low-power, intrinsically safe multi-gas microsystems for stable sampling and multi-channel response under high humidity/dust. Provide reliable raw signals for mixture identification and simultaneous monitoring of SO_2, nitrogen oxides, CO, CO_2 and CH_4.

2. Develop edge-intelligence methods for coalfield-fire combustion gases, including classification, concentration inversion, anomaly recognition, false-alarm suppression and adaptive calibration. Address mixed-signal separation, removal of environmental interference and dynamic warning thresholds.

3. Investigate effects of high temperature, heavy dust and low pressure on measurement signals. Establish compensation and self-correction to extend maintenance-free periods and improve continuous-operation reliability.

3.2 Expected outcomes and technical targets

1. Monitor at least six gases, including CH_4, SO_2, CO, CO_2, O_2 and NO_x, with expansion to additional hazardous gases.

2. Inter-channel interference error in mixed gases $\leq \pm 5\%$ FS.

3. Environmental tolerance: 0-50°C, 0-98% RH and protection rating IP54 or higher.

4. Preferred cooperation modes

Joint research and development; Commissioned development; Joint laboratory/cooperation base; Researcher exchange/training.