INDIRES Newsletter

Information Driven Incident Response

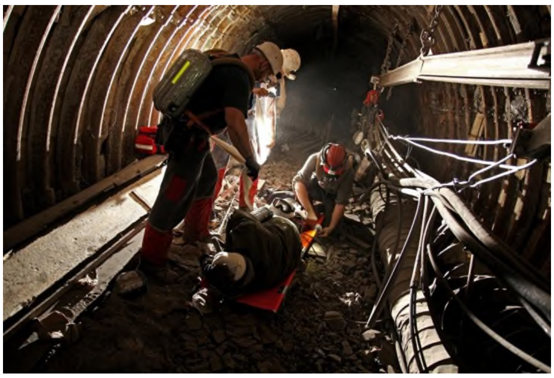
September 2018

INDIRES
Information Driven Incident Response

Newsletter
September 2018

Table of Contents

Lack of information is a major hindrance to the effective response to a serious underground mining incident such as a fire, flooding, an explosion, or a fall of rock. INDIRES is a research project, the aim of which is to allow the rapid acquisition of information and to permit communication between affected miners, rescuers and mine management. By improving the efficiency of mines rescue operations, it is expected that this initiative will help protect the welfare of personnel and the future operation and profitability of the mine.



INDIRES is a three-year collaborative project. The interdisciplinary consortium comprises 10 organisations from five member states of the European Union. Partners include two coal producers, three research organisations, three universities, a civil engineering consultancy and an equipment manufacturer.

Front Cover: Mines Rescue Practice
Photo: Premogovnik Velenje

This project has received funding from the Research Fund for Coal and Steel under grant agreement No 748632.

A Year Closer to Making a Difference

*As the INDIRES research project enters its second year, Newsletter Editor **Mike Bedford** looks back on a year of progress in achieving our aim of making coal mining safer and more profitable.*

The Challenge

We might like to think that serious mining incidents are a thing of the past, but a review of recent events suggests otherwise. This is an issue that we can never afford to become complacent about.

In August 2010, a rock fall in the San Jose Mine in Chile cut-off 31 miners. In time it was discovered that all had escaped serious injury and, after 69 days, each of them were rescued. However, it's not hard to imagine how the outcome could have been so very different. In the same year, an explosion at Pike River Mine in New Zealand resulted in the death of 29 miners.

The Soma coal mine in Turkey experienced one of the worst mining disasters of recent times. Also in 2010, an explosion and subsequent fire caused the loss of no fewer than 301 lives.

Effective Communication

Although the death toll was not as great as in the 2010 disasters – not that any loss is acceptable – lessons can be learned from a spate of accidents in American coal mines in 2006 and 2007. Drawing on the experiences of those involved in coordinating the rescues following these high-profile disasters – including those at Sago Mine, West Virginia, in 2006, Aracoma Alma No. 1 Mine, West Virginia, in 2006, Darby No. 1 Mine, Kentucky, in 2006, and Crandall Canyon Mine, Utah, in 2007 – researchers cite poor communication as their second main hindrance after preparation and planning (see *A Study of First Moments in Underground Mine Emergency Response* at **www.cdc.gov/niosh/mining/UserFiles/works/pdfs/asofm.pdf** for more detailed information). The researchers concluded "Communication and information are critical. Even with a good plan, escapees and responders cannot respond adequately without accurate and timely information.... Although this study was not focused on technology, researchers recommend investing in and remaining current in communication technology." It should be noted that 19 miners perished in these four disasters, some of whom may have been alive today had improvements to information and communication technologies been available.

Helping to prevent the loss of life due to poor communication during rescue operations was a key motivation in proposing the INDIRES project. In considering the requirements, we interpreted the word "communication" in its broadest sense and are, therefore, researching several initiatives to help the flow of information during the critical initial response to a serious mining incident. Our work to date in some of these areas is discussed in articles in this newsletter.

It's a depressing fact that serious mining incidents – including ones like the Soma Mine disaster in Turkey that claimed 301 lives – is a threat today as it was in the 19th and early 20th century. Photo: Mustafa Karaman

Collaboration

Drawing on the expertise of several diverse organisations is important to the success of this project. Indeed, you can learn about the organisations involved elsewhere in this newsletter. However, the fact that the project consortium comprises 10 partners, spread across six cities in five different countries, means that it's necessary to pay particular attention to ensuring effective dialogue and collaboration. In addition to day-to-day communication, this is achieved via twice yearly Partners' Meetings. Two such meetings were held during the first year of the INDIRES project – one in Wales and one in Poland – and you can read about these important get-togethers in these pages.

The Way Forward

Several of the research initiative started in the first year of INDIRES will continue into the second and final years of the project and some new strands of work will commence. We'll report on the next 12 months of activity in the second newsletter which will be published in September 2019. No newsletter will be published at the end of the project, but details of the work throughout the complete three years will appear in a Final Technical Report which will be published, after the completion of the project.

Dissemination of the results is vital to achieving the aims of the project and several initiatives will achieve this throughout the course of the project and, particularly, towards the end. In addition to placing papers in academic journals and speaking at conferences, we will provide full user documentation for each developed technology and hold a workshop to which stakeholders will be invited.

The INDIRES Consortium

We examine the organisations who are working together to ensure enhance safety in mining by empowering rescuers with better means of effective communication.

Research in INDIRES is being carried out by a well balanced, interdisciplinary consortium. This guarantees the necessary balance between the theoretical and the practical aspects of the work, and between the essential elements of pure research and the requirements of the rescue community and coal producers.

The consortium, comprising organisations from five European Union member states, includes four research institutions (DMT, EMAG, GIG and KOMAG), some of which also provide consultancy and act as equipment manufacturers, two coal producers which also have full-time rescue teams (Premogovnik Velenje and Polska Grupa Górnicza), a civil engineering company specialising in underground work (Geocontrol), and three universities (University of Exeter, Silesian University of Technology and Universidad Carlos III de Madrid).

Here we take a look at these organisations that will be delivering the innovative work within INDIRES.

University of Exeter

The University of Exeter is acting as Project Coordinator for INDIRES.

The University combines world class research with excellent student satisfaction at its campuses in Exeter and Cornwall. It is a member of the Russell Group of the UK's leading research-intensive universities. Formed in 1955, the University has 21,273 students from more than 130 different countries. Its success is built on a strong partnership with its students and a clear focus on high performance. Recent breakthroughs to come out of Exeter's research include the identification and treatment of new forms of diabetes and the creation of the world's most transparent, lightweight and flexible conductor of electricity.

The University was voted the Sunday Times University of the Year 2012/13. It is ranked amongst the UK's top ten universities in the Higher Education league tables produced by *The Times* and *The Sunday Times*. It is also amongst the world's top 200 universities in the *QS* and *Times Higher Education* rankings. Exeter has always been among the leaders for student satisfaction, never having been outside the top ten in the National Student Survey.

Camborne School of Mines

In this project, the University of Exeter is represented by its Camborne School of Mines (CSM) which is based at the University's Penryn Campus in Cornwall.

Founded in 1888, CSM is an interdisciplinary mining school working at the forefront of a range of geoscience subjects including geology, mining engineering, mineral processing, sustainability and remediation. We deliver undergraduate, postgraduate and professional courses covering the full mining chain and lifecycle. Our superb facilities offer an experiential education, blending training with research to ensure graduates are some of the best-equipped and most employable in the sector.

CSM is a responsive, flexible and engaged partner to the industry, with a track record of delivering measurable results. We are experienced in providing services including consultancy, research and development, bespoke teaching and training to governments and international agencies, as well as the mining industry. These long term partnerships have produced significant success in consortium research, attracting funding from UK and international sources.

Of particular relevance to this project, CSM has been involved in several RFCS-funded research projects and has particular expertise in underground sensor and instrumentation technology, and several areas of sub-surface communication.

DMT GmbH & Co. KG

DMT GmbH & Co. KG is an independent engineering and consultancy company, active worldwide. The firm's activities focus on natural resources exploration, mining and coke-making technology, geotechnics for construction and infrastructure projects, safety in buildings, and product testing and measurement instrumentation in industrial settings. DMT provides individualised solutions and assistance tailored specifically to the clients' needs and serves as an impartial assessor in the aforementioned fields. DMT's services and products are developed predominantly for the mining, oil and gas, civil engineering and infrastructure, and plant and process engineering sectors.

DMT GmbH & Co. KG, headquartered in Essen, Germany, is the holding company of the DMT Group, which comprises 16 companies and 997 employees in total, operating from 30 offices around the world. DMT is a member of the TÜV NORD GROUP. The lists DMT's primary areas of expertise in its main areas of activity.

The ten INDIRES Partners represent five member states of the European Union

Geo Engineering & Exploration

Subsoil exploration and monitoring using geological and hydrogeological, geophysical, geodetical and geotechnological methods; surveying; modelling; construction planning; inspection and evaluation of earthworks; ground water control; site remediation and project management.

Mining Consulting & Engineering

Investor support, geology and mineral exploration, resource estimation, mine design and planning, feasibility studies, operational support, deep shaft engineering, strata control, backfill systems, mine ventilation and gas control, transport and logistics engineering, mine closure and remediation, mine water management.

Industrial Engineering Services

Process engineering for gas cooling, gas scrubbing, tar extraction and wastewater treatment; planning, design, construction and commissioning of plants; coal blending and coke testing.

Plant & Product Safety services

Fire and explosion protection; testing of ventilation, drinking water, cooling, extinguishing and smoke extraction systems; destructive and non-destructive rope testing; inspection; safety concepts and documentation; training and seminars.

Seismic Exploration

2D, 3D and 4D reflection seismics, refractionseismics, shallow-water seismics, vertical seismic profiling (VSP), data processing and modelling.

Products

Geo measuring instruments, shaft scanning instruments, condition monitoring systems, sensors, coking technology, test products and stands.

EMAG

Instytut Technik Innowacyjnych EMAG (the Institute of Innovative Technologies), is a research and development institute, with activities ranging from hazard monitoring and safety systems, automation systems and intrinsically safe equipment, to mobile inspection platforms and informatics.

The Institute has been in business for over forty years. EMAG offers specialised services and innovative business solutions. It conducts industrial research and development work in many areas, such as monitoring, applied IT, power electronics, automation, safety and industrial metrology. Its fields of activity also include computer systems, telemetry, specialised medical measurements, and management of technological and business processes. EMAG's engineering skills, experience and infrastructure have been used to implement national research projects, research programmes of the European Union, and programmes implemented under European funds.

Our Mission

We develop new and improve existing devices, technologies and systems that serve to streamline production processes, increase work safety and improve quality of life. This concept stems from our belief that science should serve humanity. Hence, in its operations, EMAG follows two rules. First the rule of utility – the research and development work respond to the results of analyses and the needs of industry, administration and the social sphere. Ssecond, the rule of complementarity of research processes and implementation processes.

The basic mission of EMAG involve the following activities:

- developing innovative solutions,
- conducting research and development work in the areas of widely understood computer science,
- initiating research problems in non-scientific areas,
- adapting research results to new applications,
- improving existing devices, technologies and systems that contribute to more efficient industrial processes, better work safety and life quality,
- maintain and improve laboratory-research infrastructure for development of science in the areas of economy – Direction Industry 4.0, public administration, national safety and Internet of Things; and stand against social exclusion.

What we Do

We deal primarily with research and development (R&D), specialised research services, certification and approvals, as well as expert opinions mostly in the following fields: electrical power engineering and automation; system, operational and local monitoring; applied IT; and industrial metrology. We carry out domestic and EU research programmes, as well as targeted projects and projects executed as joint ventures with SMEs. Innovations developed in EMAG are commercialised by the Scientific and Industrial Centre of EMAG, both in Poland and abroad.

Experience

For 40 years we have been providing solutions to various Polish businesses in the form of modern products and services. We cooperate closely with the mining industry, particularly hard coal mining, which has been our traditional area of interest. We are primarily renowned for solutions in industrial automation, gas monitoring, telecommunications, electrical engineering, geophysical systems, and industrial metrology. We are recognised in all places where minerals are extracted. Our innovations have been implemented in overseas mines with extremely difficult conditions of mineral exploitation (in China, Russia, Vietnam, Colombia, Czech Republic, Belarus and Ukraine), as well as in the majority of Polish hard coal mines and industrial plants of different sectors. We support other industrial branches and social areas of life – public administration, public safety, defence, health service – mainly in the range of applied IT.

Geocontrol SA

Geocontrol is a civil engineering company established in 1982, independent of any construction companies, manufacturers or equipment suppliers and financial institutions. Initially specialising in rock mechanics, since 1987 the company has been orientated towards project design and site supervision of tunnels, as well as geotechnical applications, both in the civil engineering and mining sectors.

Geocontrol offers advanced technical solutions through its own specific methodologies, obtained through R&D&I projects, which can be applied during the design phase (RME, RMR14, ICE) and during tunnel construction (e-CONV, ae-MAT TBM, ae-MAT EPB y EEE).

Services provided by Geocontrol include basic engineering, feasibility studies, detailed engineering, technical advice during construction, supervision and control of the works, structural and safety installation inspections, refurbishment projects for all kind of tunnels (including subways, roads, water transportation) and rock mechanics.

Geocontrol has its headquarters in Madrid, Spain, and has a significant presence in Latin America through its offices in Colombia, Peru, Chile and Brazil.

Geocontrol has implemented and certified a quality, environmental and safety and health at work management integrated system according to ISO 9001: 2008, ISO 14001: 2004 and OHSAS 18001: 2007 with the following scope:

Engineering services for the development of tunnel and underground work studies and projects, including geological-geotechnical studies, tunnel safety installations and mining geotechnics.

Geocontrol has dedicated significant resources to R&D&I activities because it is fully aware that the main way to offer its clients new services of the highest quality, as well as increasing its productivity, is through research. Geocontrol has developed R&D activities since 1987 through projects related to the company's activities of ground characterisation, design of tunnel supports, tunnel safety and technical advice during construction. The main R&D&I projects in which Geocontrol has participated are as follows:

Projects Fully Financed by Geocontrol

- Rock Mass Excavability Index (RME)
- Electronic Convergences (e-CONV): control of tunnel stability
- Project viewer (VT 2001)

Projects Financed by Geocontrol & Centro para el Desarrollo Tecnológico Industrial (CDTI)

- Prediction of cutter wear consumption in TBMs (2008)
- Application of the RME index to conventional tunnel excavation (2009)
- Development of a new system to predict ground changes ahead the TBM (2009-2011)
- Automatic and real-time measurement of the convergence in tunnels (2010)
- New High Tech Shotcrete: Nanoshotcrete (2011-2014)
- Update of the Rock Mass Rating Index (RMR) to improve its performance to characterize the ground (2012-2014)
- Energy Efficiency in Tunnels: ENERTUN (2014-2015)
- Control of the performance of shield TBMs using the Excavation Specific Energy (2015-2016)

Projects Funded by EU Framework Programme

Geocontrol has participated in more than 20 projects within the Framework Programmes, partially financed by the EU. These projects usually have a three year duration, and are completed by Geocontrol working together with other European companies from Germany, UK, France and Poland. In some of these projects Geocontrol has participated as Coordinator.

Głowny Instytut Górnictwa (GIG)

The Central Mining Institute (Główny Instytut Górnictwa – GIG) is a major Polish research institution. Driven by technical and human potential, its extensive research capabilities enable it to respond appropriately to the needs of the mineral mining industry, as well as other sectors of the economy. The Institute is committed to exerting a positive impact on the relationship between the industry, its people, and the natural environment.

One of the guiding principles of GIG is to pursue multiple paths towards sustainable development. As far as the mineral mining industry is concerned, this involves ensuring its economic efficiency to improve living standards for both employees and local communities, while keeping in mind the occupational safety and the condition of the environment, and also the availability of resources.

Since its beginning, the key issues that the Institute has been committed to investigate are occupational safety and technological progress in mining, especially in hard-coal mines. Indeed, GIG consistently ventures into new areas of research and, in so doing, it responds to the challenges that the modern-day Polish and European economies are facing.

Some of the problems that these challenges relate to include the development of clean coal technologies, the geological storage of carbon dioxide, the generation of hydrogen by means of underground coal gasification, the reuse of methane derived from coal mines and water mining, high-technology for the sustainable development of mining areas, and research into social change within industrial regions. All these are new developments, so there is yet much to be done, hence the interest that it sparks both across Europe and worldwide.

Clean coal technologies (CCT) represent, by far, the top priority for GIG, as both the future of Polish coal and the energy security of our country are conditional on their development. CCT is an umbrella term for low-environmental-impact industrial technologies that involve coal, be they in the mining, energy or chemical industries. A state-of-the-art research complex, the Clean Coal Technologies Centre, was launched this year with a view to gaining new insights into these technologies and other fields of interest. In investigating the above mentioned research area, we also keep in touch with developments related to climate change and clean energy. For several years now, the Institute has been heavily involved in developing a safe, underground, coal gasification technology. Once implemented, as well as facilitating better use of Polish coalfield resources in the future, it will also help achieve a very clean energy product. Other projects focus on reducing methane emissions attributable to the working of coal fields. This is of importance for occupational safety and environmental protection, and also for reusing this gas for energy. Clean geothermal energy, derived from mining water pumped out to the surface, is also a subject of major interest to GIG's research teams.

Significantly, the proposed technological solutions are meant to take into account the social factor, with the emphasis on the social acceptability of the individual technologies. For this reason, in keeping with the principle of sustainable development, GIG laid out an original methodology to assess the eco-efficiency of technologies. By developing technologies that qualify as sustainable, the Institute feeds into the EU policy of implementing the Environmental Technologies Action Plan. These are only the core areas of our effort, since it would take a great deal of time to discuss all areas of interest which include land protection, waste management, water management, air protection, noise prevention, and many more. What is significant is that, in the entirety of its research policies and activities, the Institute is committed to delivering something new and innovative, and also to keep in touch with the needs of the markets in which our clients operate. It is they who set the bar high for science, as the problems of the modern-day industry, that the Institute is trying to solve, are becoming more and more difficult and complex.

Department of Extraction Technologies and Mining Support

This department is focused on development, design and maintenance of different types of mining support and underground construction. Our main activities are as follows:

- design and selection of mining supports such as steel yielding supports, rock bolts, concrete and shotcrete lining,
- design and selection of powered roof supports for site specific geological and mining conditions,
- design of mining supports for mining gallery junctions ,
- design of steel arch supports and accessories,
- design liquidation of mine workings connected with the surface (mine shafts, adits etc.),
- development of technical and technological projects in terms of mining support repair,
- research of rock mass and rock parameters surrounding mining excavations,
- research of mining support technical conditions,
- research work in terms of underground construction (mine shafts, roadways, adits etc.),
- technical inspection of vertical mine shafts by use of climbing techniques,
- defining the conditions of effective and safe maintenance of long wall and roadway excavations,
- assessment of effective and economical coal deposit extraction with a long wall or alternative system,
- stress-strength analysis of mining supports and their components,
- development of specialised software,
- numerical modelling of rock mass using FLAC, FLAC3D, UDEC, Phase, RS3,
- numerical modelling of buildings, machines and equipment used in mining using COSMOS/M, ANSYS,
- development of research equipment and software,
- development of innovative solutions for mining,
- training in the terms of mining support design, use and maintenance.

Instytut Techniki Górniczej (KOMAG)

The mission of KOMAG, Instytut Techniki Górniczej, the Institute of Mining Technology, located in Gliwice, Poland, includes the creation and commercialisation of innovative solutions in the scope of mechanical systems, mechatronic systems, environmental protection, control of hazards, work safety and the safety of product use.

KOMAG's activity incorporates scientific and research projects concerned with improvements to mining technology, haulage and the processing of minerals. The projects are oriented towards anthropo-technical systems in the aspect of reliability, work safety and comfort.

Concepts and technical documentation of innovative solutions of machines and equipment are achieved within the projects. Model, laboratory and operational tests contribute to an increase of the life and reliability of machines as well as to the improvement of work safety and comfort, having a direct impact on increased efficiency in the production and processing of minerals.

Specialist testing services of accredited laboratories, tests of powered roof support units, tests of hydraulic actuating components, environmental tests, and tests of safety of product use and material engineering tests, play a significant role in the Institute's activity.

KOMAG certifies machines and equipment within the scope of the ATEX Directive on machines and protective systems intended for use in areas at risk from explosion hazard, the Machinery Directive on principal requirements for machines, the Directive on electrical equipment for use at certain voltage ranges, and the Directive on the principal requirements for toys. Besides the certification of products, KOMAG certifies management systems.

KOMAG's significant position, both in the Polish and international research areas, has been achieved as a result of close collaboration with manufacturers and users of mining machines and equipment, as well as with scientific partners representing

Polish and foreign universities, research centres and mining supervisory bodies. KOMAG's divisions are centred around the following areas of expertise:

- powered roof supports,
- horizontal transport,
- vertical transport,
- roadway systems and hydraulics,
- long wall shearers,
- drives and control systems,
- preparation systems,
- mechatronic systems,
- ecological systems,
- applied vibro-acoustics,
- modelling methods and ergonomics,
- attestation tests, certifying body,
- testing and applied testing laboratory,
- material engineering and environment laboratory.

Polska Grupa Górnicza (PGG)

Polska Grupa Górnicza (PGG), the Polish Mining Group, was created from the former Kompania Węglowa SA company. At present, PGG has three integrated collieries based on nine member mining facilities and two independent facilities. Each mine has its own rescue team. PGG is the European Union's largest mining company, employing around 32,000 staff. The current staff has many years experience in the area of international scientific projects, such as PROSAFECOAL, MONSUPPORT and STAMS.

Premogovnik Velenje d.d.

The Velenje Coal Mine (Premogovnik Velenje d.d) operates the largest Slovenian coal deposits and one of the thickest known coal seams in the world. 165 metres thick, its lignite layers have enabled the production of over 220 million tonnes of lignite so far. Piled on wagons, it would make up a train that could encircle the Earth twice. The first mention of the coal deposits goes back to the 18th century, first drilling to 1875, and the first mines to 1887.

Daniel pl. Lapp was the first to succeed in producing significant amounts of lignite after the main lignite layer had been discovered in 1875, the year regarded as the birth of the Velenje Coal Mine. After the first shaft had been sunk, miners managed to continually increase production despite exclusively manual work. One of the contributing factors was a new railway line, which enabled sales to distant consumers.

The first thermal power plant, lignite-based, was built near the coal mine in 1905. Coal mining in the Šaleška valley experienced its biggest boom after WW II, when the demand for coal skyrocketed.

Coal production continued to increase until the 1980s when the Velenje Coal Mine accounted for three quarters of all Slovenian coal. Modern equipment and the company's own coal mining method could barely cover the demand for coal in 1980s. It was the country's former appetite for energy that made the Velenje Coal Mine reach its peak annual coal production, 5 million tonnes of coal, in mid 1980s.

Nowadays, Premogovnik Velenje is a technologically advanced company with lignite mining as its primary activity. The lignite produced in Velenje is used to power the Šoštanj Thermal Power Plant, which uses the annual coal output to generate one third of all electric power consumed in Slovenia. In the Velenje Mining Method, the coal face is divided into the footline section and the hanging wall section. The footline section is 4 to 5m high and secured by a hydraulic support system which allows mechanised exploitation by using excavation machines – shearer loaders and the conveyance of coal by using efficient chain conveyers. The hanging wall section, measuring 5 to 17m in height, is exposed to dynamic stress conditions which cause the crumbling of the coal layer; the crushed coal is then poured onto the conveyor and is promptly transported to the surface.

With over 140-years tradition in lignite mining, the mine is firmly rooted in the Slovenian energy economy. At today's mining output, there are enough deposits of the Velenje lignite for another four decades of coal mine operation. Due to changes in the energy industry and envisaged changes in the operation of the thermal power plant, mining sites will close before the lignite reserves are exhausted.

To rationalise the process of coal production, developmental projects are underway in Premogovnik. Included here are projects in clean technologies for coal consumption, electric power, roadways, transport and logistics, optimisation and automation of coal transport, the ecology of work, management of people at work, and occupational health and safety.

The developmental nature of various projects shows promise that the company's new activities will turn out to be as important for the life of the Šaleška valley and the wider region as the operation of the coal mine has been for Slovenia as a whole.

Premogovnik Velenje, an associated company of Holding Slovenske Elektrarne, excels in its great sense of social responsibility, both in terms of solving environmental issues, securing sustainable development, and preserving jobs for the life of the Šaleška valley and wider region.

Coal mining is often regarded as an activity with adverse impacts on the environment. Due to economic and social pressures, the environment is sacrificed in many of the areas with reserves of this important energy source. Aiming to bring coal mining in line with the principles of sustainable development, Premogovnik Velenje has reduced its adverse environmental impact substantially.

You can tour the virtual mine at **www.rlv.si/si/VRRLV/nacrt.html**.

Silesian University of Technology (SUT)

The Silesian University of Technology (SUT) was established in 1945 as the scientific and teaching centre of Upper Silesia, the most industrialised region in Poland and one of the most industrialised in Europe. It is the oldest technical university in the region and one of the largest nationwide.

Over 60 study programmes and over 200 specializations related to a vast range of engineering studies are offered in 15 faculties, including one college and research institute. Currently there are over

21,000 students, including over 15,000 in full-time study. The institution offers first degree studies – Bachelor of Engineering, second degree – master studies, and third degree – doctoral, all available for either full-time or part-time study.

A rich didactic offering and the high quality of education contribute to the fact that SUT is one of the leading technical universities in Poland. Our University ranked 4th in Poland in the recent Ranking of Engineering Studies, and 5th in the Ranking of Technical Universities in Poland, both issued by the "Perspektywy" Education Foundation. It is also the best university in the Silesian Voivodeship.

As a prestigious European technical university, SUT also conducts innovative scientific research and developmental work.

SUT is represented in INDIRES by the Faculty of Electrical Engineering and the Faculty of Mechanical Engineering.

Faculty of Electrical Engineering

The Faculty of Electrical Engineering was formally established in 1945. Over the years, the organisational structure of the Faculty has changed numerous times. In 1994, the Faculty launched PhD studies for the first time. Since the very beginning, the Faculty has offered full-time and part-time courses in Electrical Engineering. Following the changing market requirements and expectations of employers, a course in Electronics and Telecommunications was launched in 1995 and, in 2008, two new courses, Computer Science and Mechatronics, were introduced. In 2013 a new course – Power Engineering, with the unique specialisation of Prosumer Power Engineering, was launched.

Research activities concern electrical engineering, electronics, telecommunications, power engineering, computer science, mechatronics and optics. There are over 40 laboratories equipped with electrical, electronic, computer and telecommunication instruments. We cooperate with over 60 universities world-wide.

The Faculty has close cooperation with almost 100 Polish and foreign industrial companies, representing every speciality of electrical engineering: electronics, power engineering, telecommunications, optoelectronics, robotics, computer and measurement science, and electrical engineering in transport.

Faculty of Mechanical Engineering

The Faculty has developed industry collaboration over many years in the fields of industrial automation and robotics, machine building, and materials engineering, as well as research centres. This is one of the factors stimulating the development of the laboratory and teaching base of the Faculty. These activities allow students access to the latest technologies and equipment used in industrial production, and the Faculty offers the possibility of practical verification of theoretical knowledge and conducts interesting research. The Faculty offers specialisations for 2nd level studies in cooperation with, and under the patronage of, leading domestic and international companies in the field of advanced technology.

Universidad Carlos III de Madrid (UC3M)

The University Carlos III of Madrid (UC3M) was founded in 1989 as a public university. From the outset it was intended to be an innovative, efficient, public university providing teaching of the highest quality and focused primarily on research. Today, with over 1,700 employees and 18,000 students, UC3M aims to contribute to the improvement of society through teaching of the highest quality and cutting edge research in line with stringent international guidelines. The University aspires to excellence in all its activities, with the aim of becoming one of the top academic institutions in Europe. UC3M actively encourages the personal development of all those connected with the higher education community. All activities are guided by the values of merit, ability, efficiency, transparency, fairness, equality and respect for the environment.

Department of Systems Engineering and Automation

The Department of Systems Engineering and Automation of UC3M, is one of the largest in the country providing a broad range of educational and research opportunities. Its primary mission is to provide students with the best possible education to enable them to become wise and knowledgeable leaders in the Spanish and European Union industry, government, academia, and other areas of society.

At the graduate level, the department's mission is to provide students and researchers the opportunity for team-oriented and cross-disciplinary research and advanced training in their chosen areas through the International Master in Robotics and Automation, and PhD in Robotics.

RoboticsLab

Currently, the RoboticsLab team is comprised of more than 70 full-time researchers from 10 different countries. The main research areas include, but are not limited to, robotics and automation in construction, maintenance and inspection of civil infrastructures, mobile robotics, climbing robots, legged and humanoid robots, intelligent control, mobile manipulators, computer vision, and human-robot interaction.

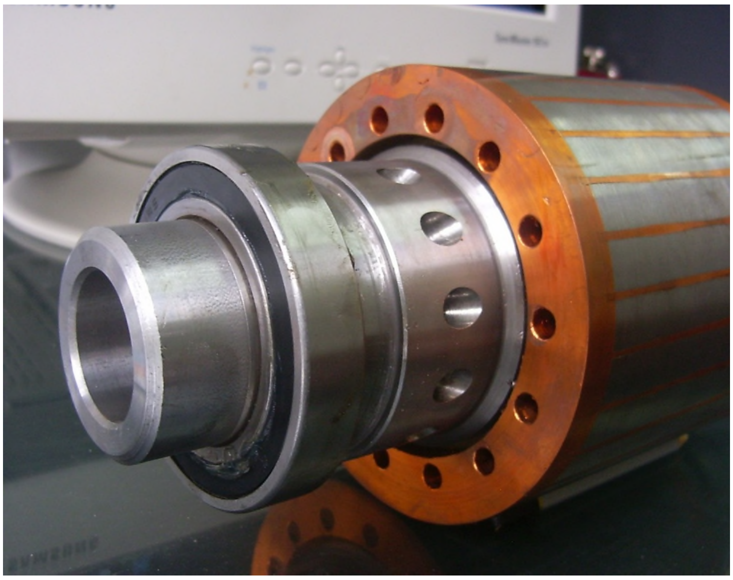
The team's work focuses on spreading their knowledge in the industrial applications of robotics, participating intensively in numerous collaborative national and international R&D projects, under the HORIZON 2020 programme, among others, as well as with many companies and institutions.

Enhanced Drilling by Torsional Vibration

***Tomasz Trawiński** and **Marcin Szczygieł**, of the Silesian University of Technology,* *describe their research and into innovative methods of drilling, utilising torsional vibration acting in the plane of the drilled wall.*

Overview

The Silesian University of Technology has been working on developing a new method of drilling. This method will help the rescue team by providing a portable rig for quickly removing any collapsed debris. Compared to the well-known method such as impact drilling methods, torsional vibration uses a frequency comparable to the natural frequency of the rocks being drilled.



View of Rotor of Torsional Torque Generator

There are several methods of drilling which may be used by rescuers, including impact drilling, rotary – impact drilling, and drilling by destruction of the rock mass. The latter methods were developed by KOMAG, the Institute of Mining Technology, in the previous INREQ RFCS project.

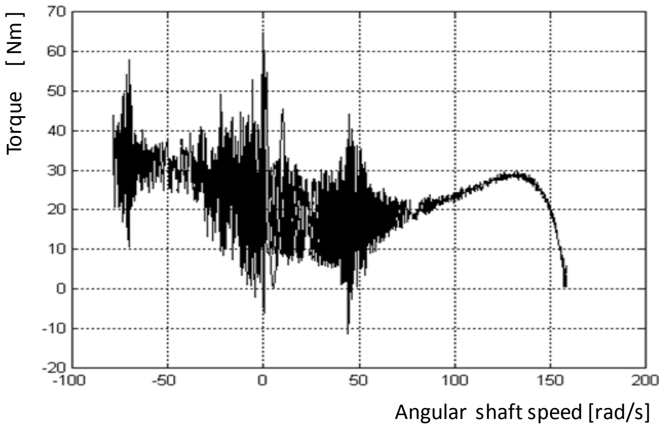
Drilling rocks can be carried out using the impact method, employing high frequency impact. The idea of vibratory drilling relies on inducing a very large number of micro-cracks, as a result of high frequency vibrations, while drilling in hard rocks. The frequency of impact depends on the rotational speed of the hydraulic motors used. For this reason, vibratory drilling can be divided into two ranges. The first is roto-vibration drilling, where the frequency range used is 60 - 85Hz. The second is sonic drilling, where the frequency of impact is 90 - 130Hz. However, this method of drilling, during rescue activities, may result in undesirable rock collapses or can cause unwanted landslide rubble.

Drilling methods based on only rotary motion is not effective for rock mining.

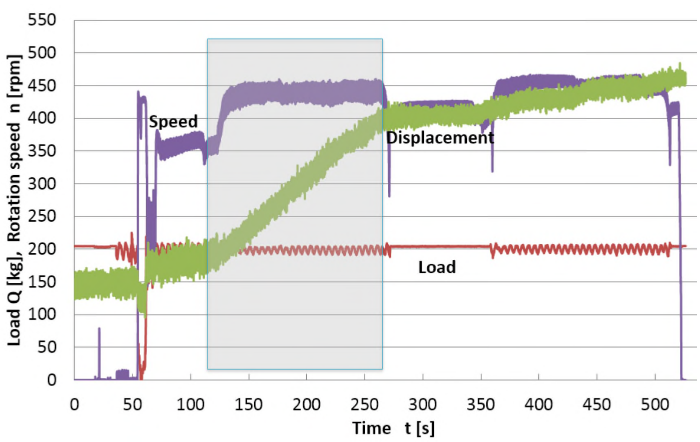
A promising alternative method of drilling was proposed by KOMAG. This method relies on holes that are drilled in the excavated wall, into which an expanding element is inserted. After wedging the expanding element in the bottom of the hole, it is pulled out, causing the fragmentation of a large amount of rock. According to KOMAG scientists, this method of drilling can be less energy-intensive, because it overcomes the tensile strength of rocks which are about ten times less than their compression strength. However, this method of drilling is time-consuming because it consists of three stages: (1) hole drilling, (2) insertion of the expanding elements, and (3) pulling out the rock mass.

It is reasonable to propose a new method of drilling, based on rotary drilling, but replacing the impacts acting in a perpendicular direction to the mining rock support by torsional vibrations equal to the natural frequency of mining rocks.

During 2003-2005, the Silesian University of Technology was involved in a project, sponsored by the Polish Ministry of Science and Higher Education,

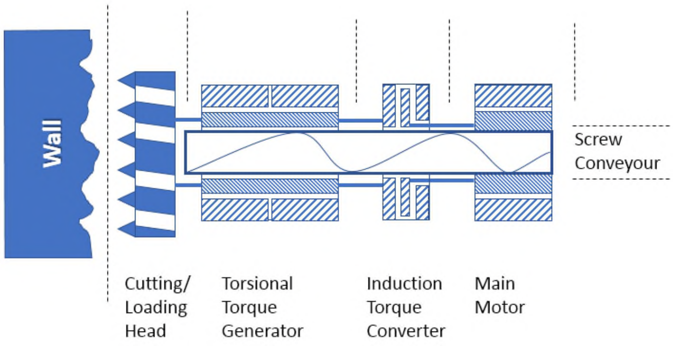


Effects of Torsional Torque Acting on the Shaft of a Drive System Showing Resonances

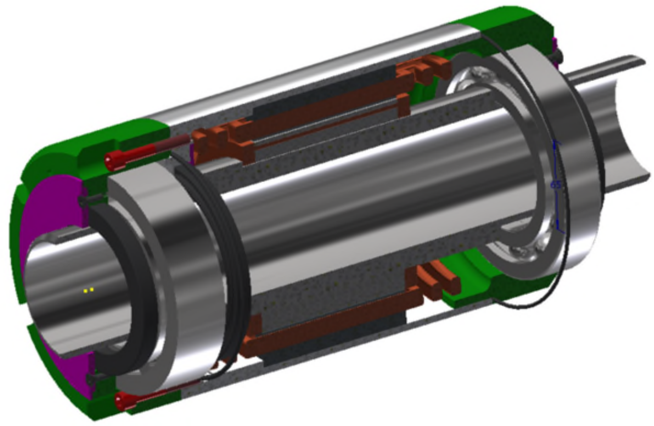


Results of Experiment – First Drilling

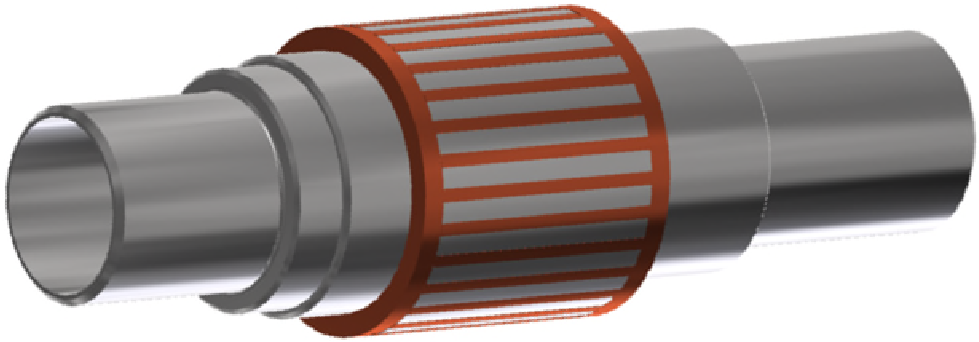
Torsional Torque Employed for Different Purposes



Cross-section Through the Drilling Rig



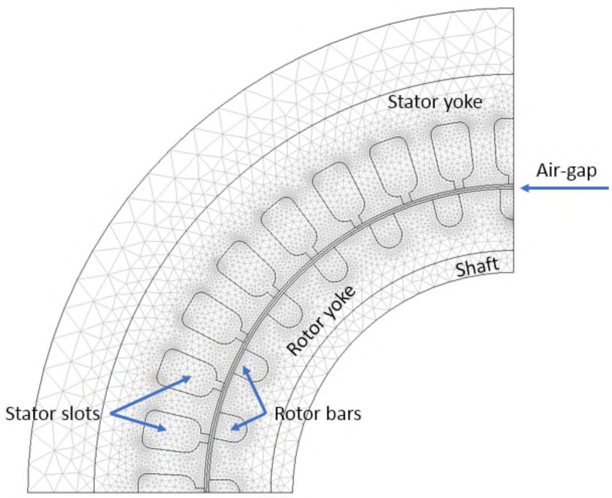
Cross-section of Designed Torsional Torque Converter



New Design of Rotor with Coper Cage and "U"-shaped Rotor Bars

into the design and construction of a natural frequencies torsional generator for drive system identification and for fatigue testing of test species. These devices used a magneto motive force (MMF) space harmonic in an air-gap to generate the main asynchronous torque, while the higher MMF space harmonics are responsible for producing additional torque. This additional torque is of an asynchronous or pulsating (synchronous) nature, and is commonly known as parasitic torque. The parasitic torque arising in a squirrel-cage motor causes many undesirable phenomena, and influences the behaviour of the machine, in both steady and transient states.

Our main concept was to introduce constructional changes to the common induction squirrel cage motor. This would enhance the pulsating torque, and by using such a new type of machine, we could investigate the natural frequency of the drive system and carry out fatigue tests of various test species. A view of the manufactured rotor of the torsional vibration generator is presented at the top of the first page. Applying the torsional vibration to the drive system allows its natural frequencies to be determined. When the frequencies of the torsional vibration equal the natural frequencies, resonant vibration occurs. This phenomenon is presented in the first graph at the bottom of the previous page. The Department of Mechatronics at the Silesian University of Technology, working in conjunction with scientists as KOMAG, decided to conduct a simple experiment with a previously constructed torsional generator for drilling in hard rock. The result of this experiment, which was carried out in KOMAG's laboratory facility (see second graph on the previous page) was very promising.



View of Quarter of Cross-section of Torsional Generator

The region on this graph which is denoted by a grey rectangle represents drilling with torsional vibration and it is clear that torsional vibration has accelerated the drilling process.

During the first year of the INDIRES project, the Silesian University of Technology's work has been devoted to the selection of the appropriate geometry for the new and unique torsional generator. Moreover, the study and development of the auxiliary components, such as the induction torque converter and main motor with permanent magnets, has already started.

The Design Process

During the INDIRES project, three main components of the new drilling rig have to be designed (see diagram above left): (1) a new torsional torque generator,

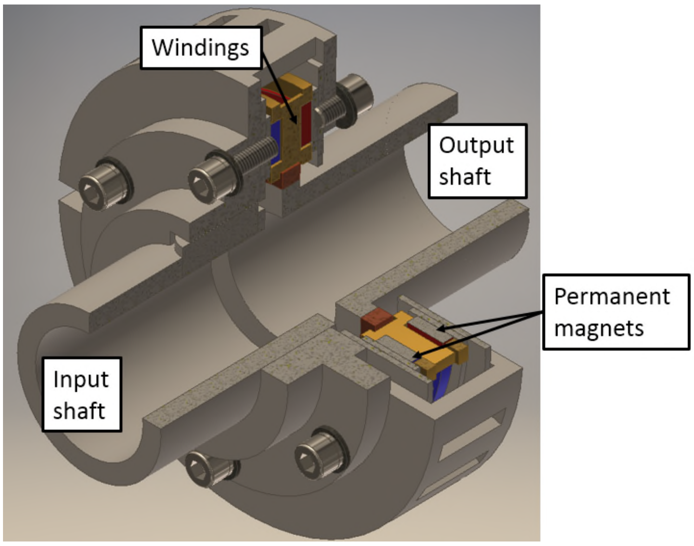
(2) an induction torque converter, and (3) a main motor with permanent magnets. Every designed component should have a hollow shaft. The empty space of the hollow shafts will be used for the implementation of an internal screw conveyor for transportation of the mined rock.

The first stage was to determine the shape of the torsional torque magnetic circuit – stator yoke and slots, rotor yoke and bars. This was done using Finite Element Methods (FEM). FEM was used for calculating the magnetic field distribution (magnetic flux density) over the stator and rotor yokes, as well as in the air-gap. The FEM calculations were made using Comsol 3.5 software. The destination geometry is shown in diagram towards the bottom of the previous page.

The aims of the field calculation were to find a shape for the rotor bar (in its cross section) which would guarantee a large number of magnetic flux density harmonics in the air-gap. The implemented geometry of the torsional torque generator, after triangulation, consists of the following number of finite elements: 4653 for the stator yoke, 2369 for the rotor yoke, 716 for the air gap, giving 7236 for the whole stator and whole 3956 for the whole rotor.

After several calculations, the final shape of rotor bar change from round to a "U"-shape. This guarantees the high amount of magnetic field harmonics and high amplitudes of torsional torque. The new design of rotor with the "U"-shaped rotor bars is illustrated on the previous page together with a drawing of the design for the whole torsional torque converter.

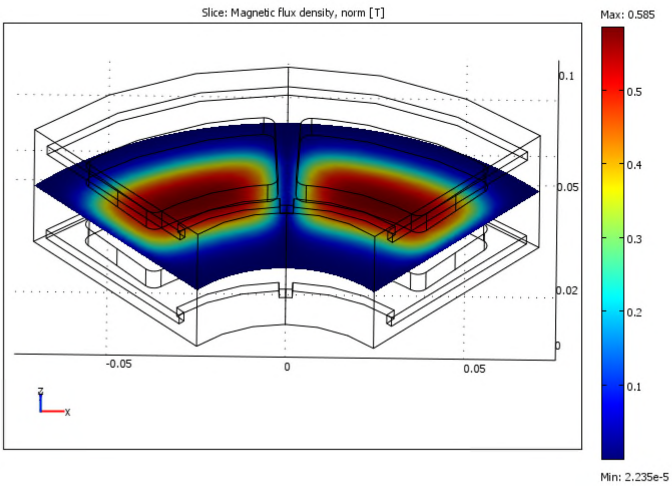
The second stage was devoted to the design of the induction torque converter (ITC). The ITC is responsible for changing the rotational speed of the main motor under high loads provided by the drill. The induction torque converter couples the main motor and the torsional torque converter by being inserted between them. Another important role of the ITC is to protect the main motor against the torsional torque generated by the torsional torque generator. It can be said that it plays an additional role as a vibration insulator. According to the concept presented in the diagram below, the induction torque converter consists of two mechanically coupled emitting disks with permanent magnets radially deployed on these disks, and of the receiving disk with inductors (windings). In the concept presented, the disks with magnets constitute the transmitting component, while the disk with inductors (windings) is the receiving component. The disks driven by the magnets induce voltage in the windings of the receiving disk. Mutual interactions between the magnetic field formed around the inductors, and the induced current in the inductors, result in electromagnetic torque generation. The electromagnetic torque generated causes a rotary motion of the receiving disk. Testing the impact of decreasing the number of poles (permanent magnets), as well as the dimensions of the magnets, and the design of a single pole on the harmonics of the averaged flux density in the area occupied by the winding of torque converter, was the analysis objective.



Cross-section of Induction Torque Converter

The Comsol Multiphisic computer program was used in the calculations of the spatial distribution of the flux density.

A neodymium permanent magnet of magnetic remanence B_r equal to 1.2 T (N37UZ Shin-Etsu Co. Ltd. rare earth magnet, H_c = 891 kA/m, BH_{max} = 271 kJ/m³) was used in the analysis, while the analysis itself, due to symmetry, was limited to the sections of the excitation circuit as it is presented in the diagram at the bottom of this page. Standard Soft Iron material (without losses) was selected as the material for the yokes from the Comsol library. The sections analyzed were discretized using 400,000 spatial components, each of which were tetrahedrons. This resulted in a total number of degrees of freedom of models of up to 70,000. A boundary condition of periodicity of the vector magnetic potential was assumed on both sides of excitation circuit (on the left and on the right side), formed after cutting the section off.

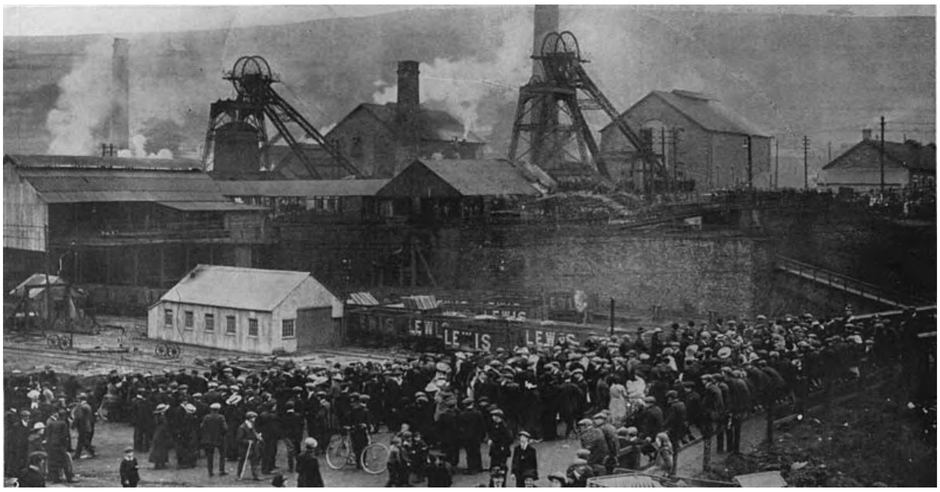


Results of Magnetic Field Calculation in Air Gap of Quarter of ITC

The important parameters of the ITC are its torque – speed characteristics. The following conclusions can be drawn from the Finite Element Method calculation. The transferred torque depends both on the input and output rotational speed of the converter. An increase of the input speed causes a proportional increase in the transferred torque. The torque decreases linearly with an increase of the output speed. The transferred power depends on the input rotational speed (excitation speed) and the output rotational speed. The transferred power increases linearly with an increase of the input speed, while its dependence on the output speed has the form of a parabola with a maximum value for half of the output for the maximum possible speed. Maximum losses are for a zero speed of the receiving component, and they decrease with an increasing speed of this component. This relationship is hyperbolic.

A Poignant Reminder

It might have taken place over 100 years ago, but the UK's worst ever mining disaster, at the Universal Colliery in Senghenydd, South Wales, provides a stark reminder of the ever present threats that. miners face. ***Mike Bedford*** *reports.*



As you can read elsewhere in this Newsletter, the first INDIRES partners' meeting took place in the former mining area of South Wales, just a few kilometres from the site of a mining accident that claimed the lives of over 400 miners and one rescuer. We learned more about this disaster during a visit to the Rhonda Heritage Park museum and were, therefore, given a stark reminder of the ever-present dangers in coal mines and the importance of our research.

On the morning of Tuesday 14th October 1913, a huge explosion in the Universal Colliery rocked the Welsh mining village of Senghenydd. At 8:00am a siren sounded in the valley, altering residents to the fact that a tragedy was unfolding. Reports referred to a cage being blown up a shaft by the blast and embedding itself in the headgear. After three weeks of rescue efforts, it was announced that 439 miners had perished. Suggestions that every single home in Senghenydd had lost someone probably weren't far from the truth. And in a chilling reminder that lessons ought to be learned from such terrible accidents, it's pertinent to report that this wasn't the first such incident at the Universal Colliery. Just over twelve years earlier, at 5:00am on Friday 24th May 1901, an explosion devastated the mine, killing 81 men. A single survivor was rescued from the workings.

In an ironic twist to this story, given the theme of our research, it seems the most likely cause of the explosion that resulted in so much death and destruction was a spark produced by operating electrical signalling equipment. By way of contrast, we have every confidence that the communication initiatives researched in INDIRES will play an important role in saving lives.

Un-manned Robotic Vehicles for Initial Information Gathering

***Noé Pérez Higueras**, of the Universidad Carlos III de Madrid, provides an overview of the work carried out to date in the development of robotic vehicles. These will be used during the early stages of the response to an incident, to provide information before human rescuers can safely be deployed.*

Overview

The Universidad Carlos III de Madrid has been working on robotics vehicles that will be able to provide a quick response to an incident in a mine environment. These robots will perform initial information gathering that can help the human rescue team to evaluate the situation and make informed decisions. In the mining context, information refers to verbal exchanges between all combinations of miners and rescuers, underground and on the surface, plus real time data indicating environmental conditions in the mine and the location and well-being of any trapped or missing miners.

A mine, following an incident, is a challenging environment for robotic vehicles.

These robotic vehicles must fulfil different tasks. First, they should be able to cover large areas of a mine in a reasonable time. Then, once they reach the approximate area of the incident, they should be able to explore it autonomously. If necessary they should be able to access areas through fallen rocks and/or poor visibility caused by dust or smoke. In such conditions, the vehicles must gather as much information as possible.

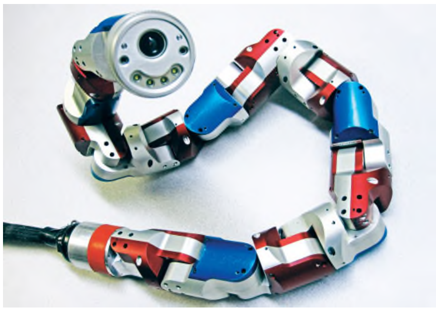
Video streaming, an acquired 3D map of the area, and data on environmental conditions such as temperature, methane and carbon monoxide concentration, are valuable to the rescue team.

Using this information, rescuers can determine the extent of any fire and predict its progression. They can also become aware of hazardous areas to avoid and effectively plan evacuation routes.

During the first year of the INDIRES project, Carlos III University's robotics work has been devoted to the selection of the appropriate locomotion methods for a team of robots. Moreover, the study and development of different 3D navigation systems has started.

Locomotion Methods

Operating in an underground mine will normally require several different types of vehicle. The vehicles should generally be operable throughout a mine

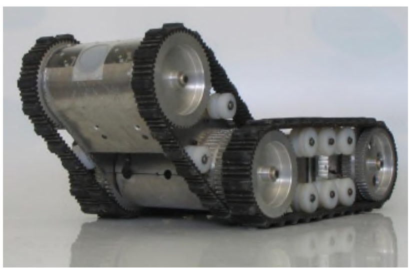


Crawling Robot

Legged Robot

Unmanned Aerial Vehicle (UAV) – Quadrotor

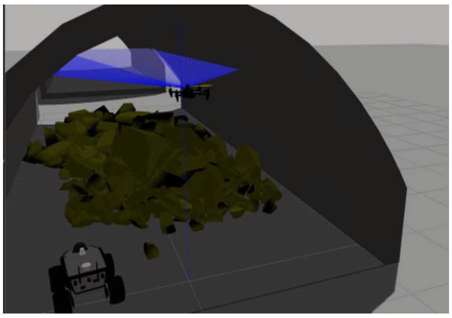
Small Unmanned Aerial System (SUAS)

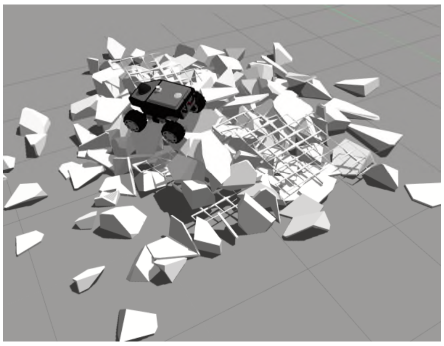


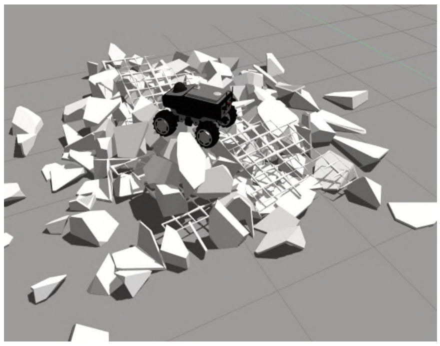
Skid Steering Ground Robot

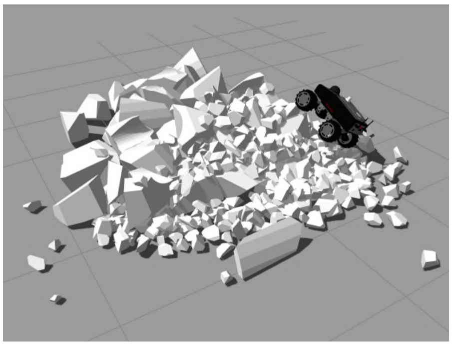
Four Wheeled Ground Robot

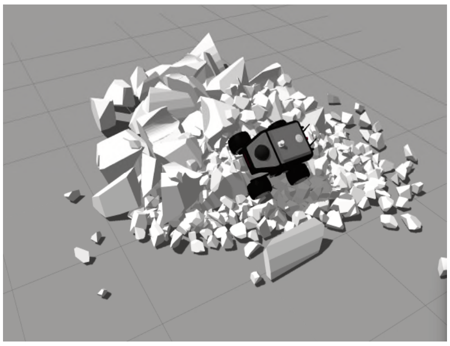
Examples of Different Robot Locomotion Methods











Top-left: Simulation of a Ground Robot and a UAV in a Collapsed Mine Environment

Other Images: Simulation of a Ground Robot Traversing Falling Rocks

and not restricted to a limited number of places, for example where ramps and drifts are present.

The mine presents a unique and tough environment for mining vehicles due to the exceptional amount of wear and tear on components such as tires, hoses and electronics, because of the tough and harsh environment. In such environments, the design of mining vehicles is often distinguished by a compact design and rugged construction.

The general specifications for the system composed by the unmanned vehicles (UV) to be developed in this project are summarised as follows.

An optimised mechanical structure is required to allow the UV locomotion in environments with a variety of obstacles such as parts of damaged machinery and equipment, fallen rocks, damaged installations, etc.

A broadband communication system is required with a range of more than 500m in a closed subterranean space from a blockage to the site of the incident.

An effective control system is needed for the UV.

A sensory system will be used for collecting data and signals from the area affected by the catastrophe.

Associated with the sensory system, methods are needed to create maps of an unknown environment and for autonomous navigation in a known environment.

A knowledge-based methodology and system are required to help the planning of the rescue mission in a hazardous and inaccessible subterranean space affected by a catastrophic event.

The locomotion system is the main factor to be decided, when selecting any platform, or combination of platforms, that need to cover large areas of galleries in a minimum time. Suitable robotic platforms are differentiated by different methods of locomotion and can be described as flying (UAVs), ground robots, and climbing and snake-like (crawling), as depicted at the bottom of the previous page.

To analyze and compare different locomotion methods we needed to focus on the following parameters.

Careful attention was given to the environment in which the robot will be deployed. Underground mines are probably one of, if not the most, challenging environment for robot locomotion.

Vehicle manoeuvrability is also very important. The characteristic mobility is defined by the vehicle's motion capabilities. Generally speaking, a vehicle should be able to traverse over unstructured terrains like stairs, ladders, fences, rock fields, sand, and maybe over water.

Other related factors that have been considered are speed, autonomy, energy efficiency, ease of deployment, weight, size and payload constrains.

Different locomotion methods have unique advantages and disadvantages as described below.

Snake-like or crawling vehicles are especially suitable for extremely complicated environments. Such vehicles – comprising a high number of segments – have the advantage that they can crawl over rocks, even in flooded conditions. The main drawback of this type of vehicle is the limited area knowledge, comprising a local view only, the understanding of the global rescue scene being complicated and sometimes not possible.

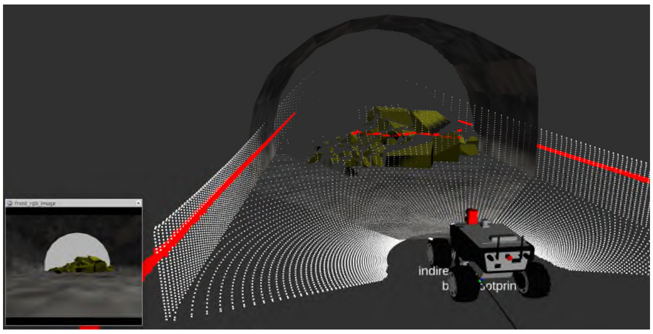
Climbing vehicles have a particular advantage in their ability to climb in the rescue environment using special types of legs that allow them to walk on the ceiling or walls. The attachment mechanism is the crucial issue. Suction pumps, magnets and even glue attachment, as used by dragonflies, are possible, depending on the environment. There are several locomotion configurations such as four or six active legs, the locomotion control strategy being bio-inspired, e.g. ants. The main drawback is that the control of these robots is complex and the area covered is relatively small.

Flying vehicles have several advantages such as fast navigation and good incident area observation. Moreover, their potential low cost makes them very suitable for swarm configurations and substitution in the case of accidents. Nevertheless, their ability to autonomously fly in a complex and confined rescue area and their low autonomy, i.e. short flying time, are their main drawbacks.

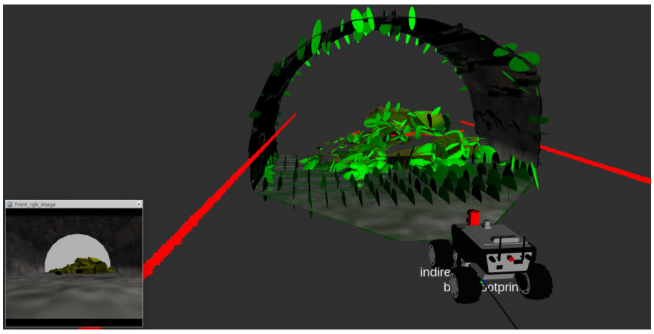
Grounded vehicles are very widespread, they can cover large areas, and have good autonomy and payload capacity depending on their size. However, the ability to autonomously overcome challenging 3D environments (such a collapsed mine) is still somewhat limited.

Taking these considerations into account, the decision on the appropriate locomotion method has also been based on results of simulations of the different types of robot in a mine environment, including those with falls-of-rock. The tools we have

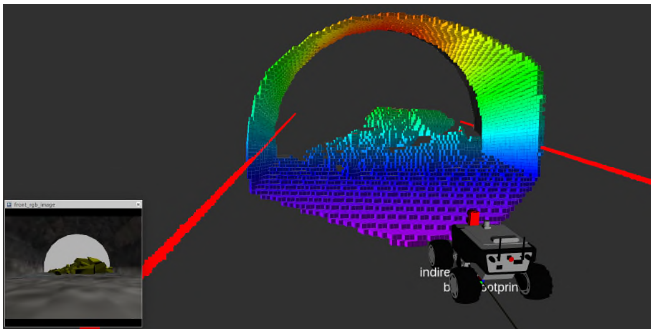
Gazebo Simulation of a Collapsed Mine



Point Cloud Representation of the Space



Normal Distribution Transform (NDT)



Octomap Representation

Simulated 3D Mine Environment (top-left) and Different Representations of the Space for 3D Navigation

used for simulation are Gazebo simulator in ROS (Robot Operating System) and Rviz, a 3D visualization tool for ROS.

The main features of these tools are that (1) they allow us to simulate and model the environment properly, (2) they provide obstacle modelling, and (3) the physics dynamics is also simulated.

Some screen captures of the evaluation of the robot capabilities can be seen at the top of the previous page.

After simulations of the different vehicle types, in a representative mine environment, we have come to several conclusions Nevertheless, no definitive conclusions can be adopted until a more precise definition is available for the payload needed for the sensors on board, and other characteristics such as autonomy, power consumption and communications.

Factors such as cost, ease of deployment and recovery, energy limitations, and safety in an unknown mine environment, must be taken into account.

The initial evaluation considers that a combination of different types of vehicles is a suitable approach. Combining vehicles with a high level of global situational understanding such as flying robots, with vehicles with local data acquisition capabilities like grounded robots, could, potentially, prove especially valuable. Therefore, the use of a ground robot, similar to the ones shown on the first page, is proposed. This robot can also carry an aerial vehicle on top that can be deployed, when necessary, in order to perform a collaborative exploration of the areas of difficult access.

Sensors and IPS

Another ongoing task is the selection of the set of sensors, to be incorporated in the vehicles, as required for navigation and pose – a robotics term that means position and orientation – estimation.

Good sensing of the 3D environment is crucial to detecting obstacles, planning possible vehicle movements, and determining the direction of approach. An accurate estimation of the 6D pose of the vehicles in the space is also required. A fusion of the different sensing sources will be employed to minimise the error in the measurements for pose estimation.

In particular, working together with INDIRES project partner DMT, we will adapt and integrate their Pilot3D positioning system, for pose estimation of the vehicles in the area, and reconstruction of the 3D environment. This device fuses the data received by a stereo camera pair and an inertial measurement unit (IMU) that uses a combination of accelerometers and gyroscopes, and sometimes magnetometers.

Autonomous Navigation

Autonomous navigation in challenging 3D environments, such as a collapsed mine, is still a complex and open problem in the field of robotics. Errors in perception and control are unavoidable and the autonomous motion planning and control of the robots is complicated.

As a test environment for simulation, we have developed a 3D mine model based on the CAD model of the real coal mine operated by INDIRES project partner Premogovnik Velenje in Slovenia. We have taken a part of this CAD, and a 3D tunnel section has been built over the selected paths. The computational complexity of the robots in this environment is very high, so we have split the 3D model into different sub-sections, in order to perform less-demanding simulations in different scenarios. Different sets of fallen rocks have also been added to these models with the aim of having a representation of a collapsed mine.

We have started to analyze the different ways of representing the 3D space in order to perform an effective navigation of the different vehicles in the environment. In the case of the flying robot, the correct identification of the obstacles and the free space is crucial in order to fly in the free space and keep a safe distance from obstacles. In the case of the ground robot, a correct identification of the 3D surface is necessary so that an analysis of the ability to traverse the environment, based on roughness and inclination, can be performed and the robot can chose the correct path to overcome the obstacles. Some examples of different representations of the space based on a point clouds can be seen at the top of this page.

Modelling Evacuation in Tunnel Environments

***Rafael Sánchez**, of Geocontrol, describes some completed projects in modelling passenger evacuation following a fire in a railway tunnel. Similarly successful results are anticipated as the techniques are being applied to the mine environment.*

In the first year of INDIRES, Geocontrol has been working on the simulation of the effects of incidents on the mine environment and infrastructure. During the next year, we will work on the related task of simulating evacuation following a mining incident.

The outcome of this research will be software that analyses human behaviour to provide information on the likely location and escape routes of missing miners. Instead of presenting the partial results of our INDIRES simulation studies, however, we thought it would be interesting to discuss some similar exercises that we have carried out into evacuation of passengers from railway tunnels during a fire, an environment that has clear similarities to a coal mine following a similar incident.

Simulation Aims

Here we present some studies by Geocontrol relating to several railway tunnels. In particular, how we have used simulations of various types in the analysis of passenger evacuation in the event of a tunnel fire.

Evacuation from rail tunnels is always one of the key aspects when it comes to the design of a tunnel's safety, as it is affected by the following aspects:

- the length of the tunnel,
- the presence of impaired occupants in the train,
- the capacity of the emergency walkway,
- the evolution of the smoke and its path in the tunnel.

Each of these aspects is relevant and a description with further detail is given in the following sections.

In this article we concentrate on the features and benefits to the end user, rather than describing the technical details of the simulation studies, although this article does show the graphical output of some of our simulation exercises. Many of the same simulation methods are being employed in the work in the INDIRES project.

Tunnel Length

The length of the tunnel is a parameter that is closely related to safety in the case of an accident that involves a fire.

If an incident occurs internally to a train when the train is in a tunnel, the first safety measure to get the train out of the tunnel. However, it is possible, in long tunnels, that the train has no option but to stop inside the tunnel.

In order to guarantee the best conditions for the evacuation of the passengers, the standards established for tunnels more than 20km long is that there must be an emergency stop station, where smoke control is possible. This sort of provision is made in many of the world's longest tunnels, for example the San Gotthard Base Tunnel which runs between France and Italy.

If the train can't reach the end of the tunnel, the driver stops the train as close as possible to the emergency stop station. Here, the exhaust system placed in the ventilation shaft is able to extract all the smoke generated by the fire. Thanks to such smoke control, the train passengers are able to reach a shelter, where there are safe conditions, and wait for the fire-fighters to arrive and rescue them.

In some tunnels, the construction of a shelter is not viable for structural reasons, and, therefore, the passengers gather in a parallel tunnel, which is considered a safe place, as in the Pajares Tunnel in Spain.

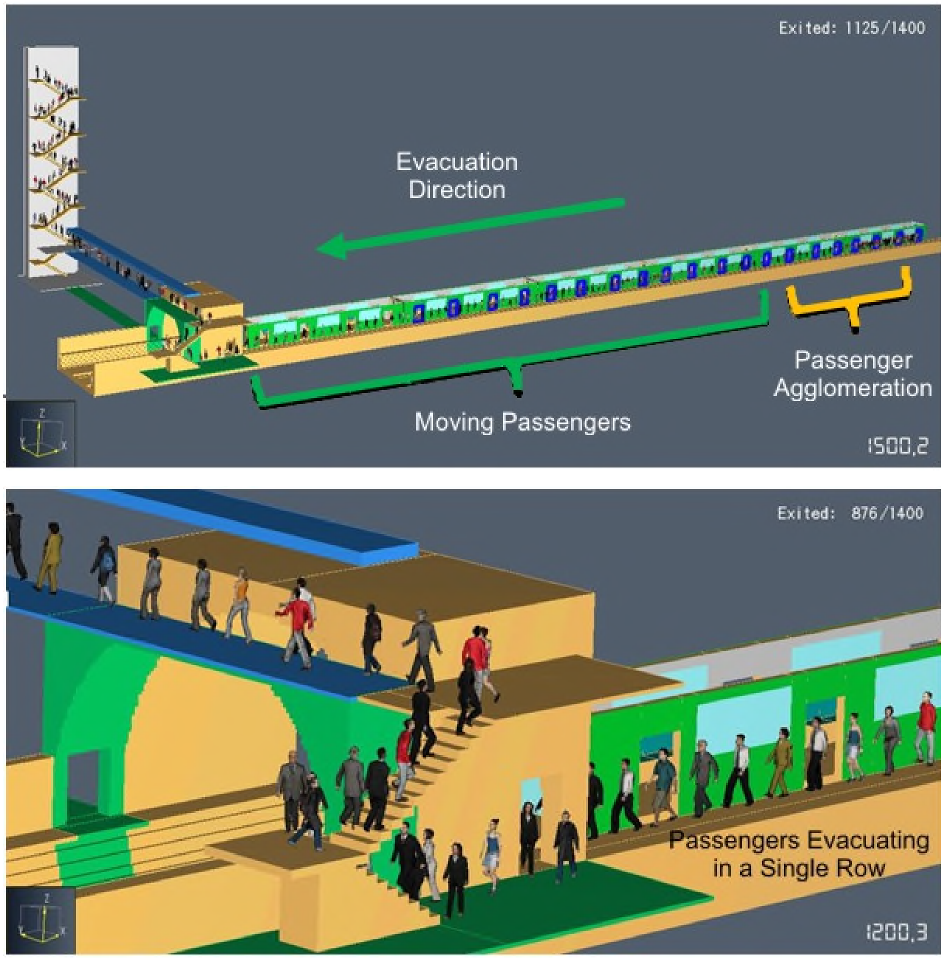
When the rail tunnel is not so long, it is not necessary to provide a ventilation system, but it is necessary to provide emergency exits at a certain separation from each other. In this case, it is quite unlikely that a train carrying out an emergency braking procedure stops in the tunnel, due to the distance needed for it stop completely. This ranges from 1,900m at a speed of 200km/h to 6,700m at 350km/h, according to data provided by the International Union of Railways.

Walkway Capacity

The capacity of the walkway is a very important factor during an evacuation in a rail tunnel. The wider the walkway, the greater its pedestrian capacity and, therefore, the sooner all the train passengers will be able to get to a safe place.

Some standards establish a necessary width of 610mm, as is the case of the subway tunnels in the future Subway Line 4 in Lima, Peru.

Studying Evacuation is an Essential Element of Tunnel Design



Evacuation Model Created for the Lima Subway Line 4 by Geocontrol

This design forces the passengers to evacuate the tunnel in a row, as illustrated in the diagrams above. This leads to a long evacuation time.

This model was created by Geocontrol with the Pathfinder evacuation software, which allowed all the design concepts and criteria considered for the Lima Subway Line 4 tunnel to be integrated.

On the other hand, in some tunnels, a wider walkway is available, and this helps to reduce the required time to reach a safe shelter or an emergency exit, as with the Camarillas Tunnel in Spain.

Smoke Evolution and Path

In case of a fire in a rail tunnel, one of the goals is to maintain an evacuation path free of smoke. This can only be achieved by having enough cross-sectional area, which allows the smoke to remain in the upper part of the tunnel thanks to buoyancy forces.

In the Otero Tunnel in Spain, which has cross-sectional area of 105 square metres, the smoke can move in the upper part of the tunnel, thereby providing a free smoke walkway in the case of a fire in the tunnel, as shown in the Fire Dynamics Simulation (FDS) exercise shown in the figure to the right.

In the Otero Tunnel, the cross-sectional area is quite large. This is quite beneficial in terms of safety as it allows, on the one hand, the smoke to spread away from the egress routes, and it also helps with the reduction of the carbon monoxide concentration, so that the harmful exposure to high levels of this gas is more limited.

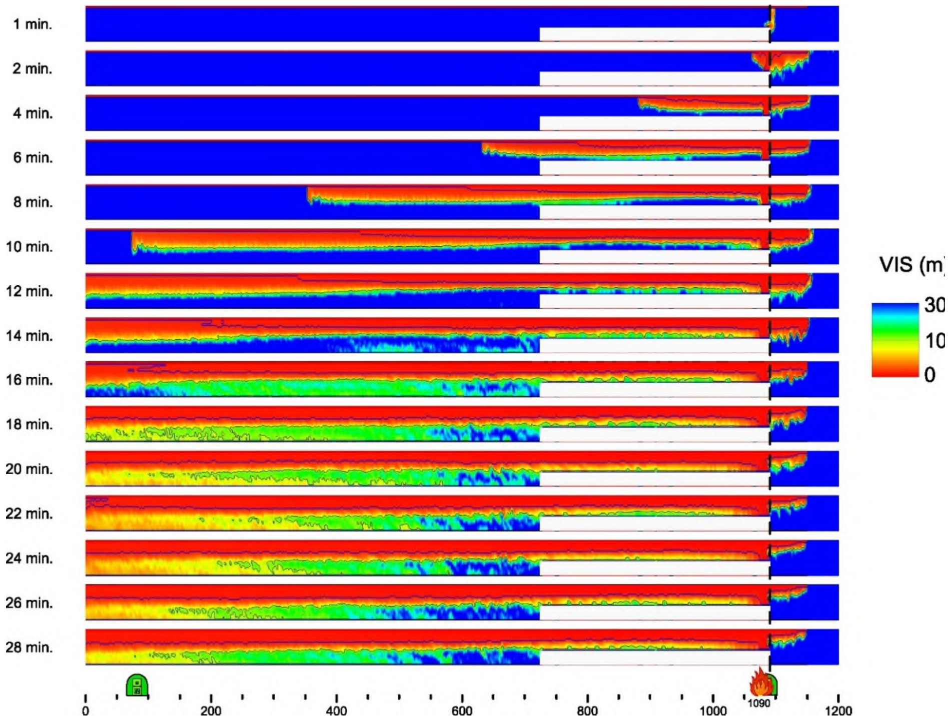
In other cases, such as the Pajares Tunnel, the cross-sectional area is smaller, which causes the smoke to fill more of the space in the tunnel, even though the smoke is found mainly in the upper part of the tunnel, as shown on the next page.

One aspect related to the smoke path, which is of great importance, is the reduction in the evacuation speed when the smoke loses its stratification and reaches the egress routes. The lack of visibility makes it harder for the passengers to find the route towards the emergency exit, thereby increasing the overall time of the evacuation.

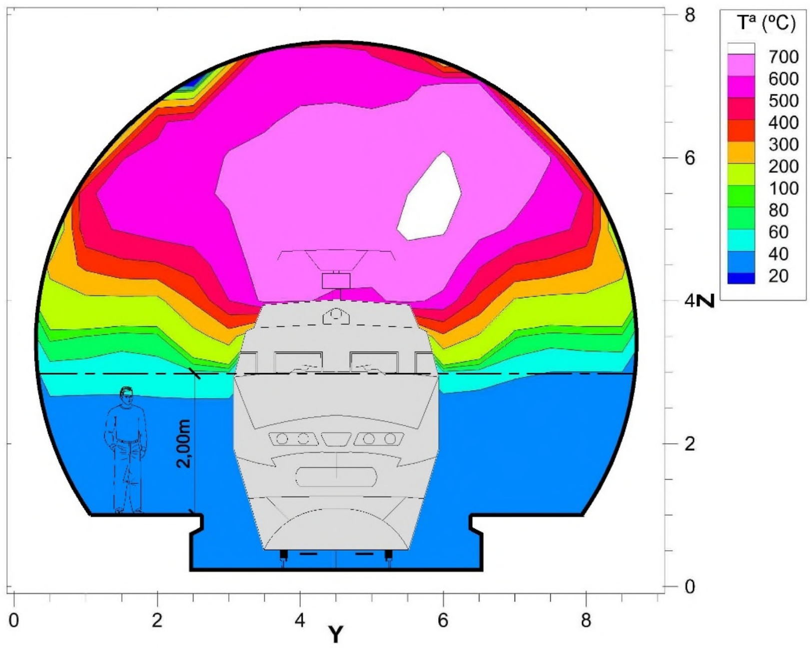
The longer the evacuation, the longer the passengers' exposure to high levels of toxic gases. For this reason, it is of great importance to achieve smoke stratification during a fire in a tunnel.

In some tests, it has been verified that a rail tunnel with sufficient cross-sectional area is able to maintain an advancing stratification of the smoke, with a smoke-free zone for the passengers, as can be appreciated in the photograph overleaf.

The stratification depends heavily on the length of the tunnel. As the smoke advances, and gets further from the fire source, its temperature decreases and this makes the buoyancy forces weaker than they are closer to the fire. As a result, the smoke looses stratification.



Visibility Evolution in Otero Tunnel, Spain



Temperature Levels in the Pajares Tunnel, Spain

Fire Test in a Rail Tunnel

If the cross-sectional area of a tunnel is large enough, the stratification can be maintained for several minutes over a variable distance, typically in the range 400 to 800m.

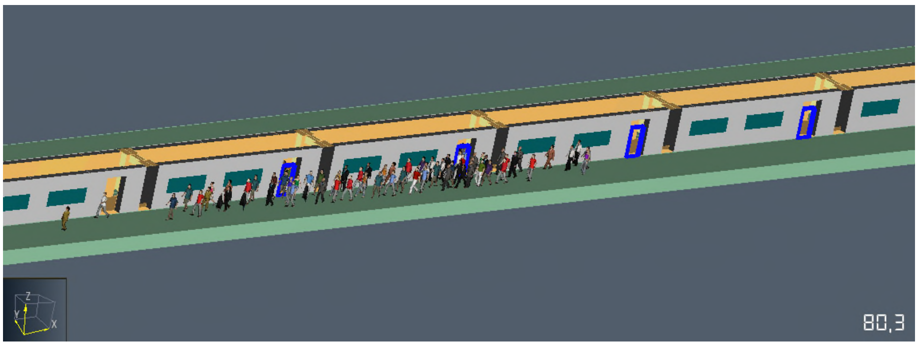
Disabled Passengers

The presence of disabled passengers in a train is a challenge for tunnel designers, because their movement is more restricted compared to people without disabilities.

Nowadays, increasingly, trains have the transport needs of disabled passenger integrated into their design. This is the case for the railway that links the Saint Lazare subway station in Paris with Versailles.

In these trains, there is always a carriage with a space for a disabled person.

A disabled passenger's speed of movement is reduced compared to that of an average passenger. Consequently, a longer time is needed for their evacuation from a tunnel.



Evacuation in the Otero Tunnel

Disabled Person During the Evacuation of the Otero Tunnel

Geocontrol has studied the effect of having disabled users in a fire evacuation in the Otero Tunnel, as shown in the figures below left. This has provided a realisation of the fact that integrating disabled passengers has a direct impact on the overall simulation.

When we investigate the evacuation process of a disabled person in a tunnel in more detail, it is clear that there are two possible scenarios, concerned with integrating disabled passengers into a simulation, which should be studied.

If the disabled person is travelling alone, then it is possible that, in the case of a fire, he will mostly be moving on his own in the walkway. In addition, his movements will not be straight, and he will interact with other passengers in the walkway, causing them also to move more slowly, because the wheelchair becomes an obstacle for some people.

However, it is possible that the disabled person is travelling with another person, who helps him when he needs to move or in the case of an evacuation. It is also likely that, in the case of a fire in the tunnel, some people will be willing to help the disabled person, as people tend to look after those who are vulnerable.

Geocontrol has simulated both scenarios in the Otero Tunnel with the help of the Pathfinder software, verifying the differences between the two assumptions.

Introducing the Project Website

*A website at INDIRES.EU is a key element in disseminating the project outcomes, leading to better adoption of the techniques developed as **Mike Bedford**, of the University of Exeter, explains.*

Innovative and ground-breaking research is of no real-world value unless the results of that research are made available to those organisations who can make use of it. In the case of the INDIRES project, that means providing details of the project outcomes to coal producers, mines rescue teams and other interested parties. Towards the end of the project, when particular products and techniques have been finalised, we intend to fully document these developments. To provide easy access to this documentation we have created a project website at INDIRES.EU from where these documents can be downloaded. The purpose of this short article is to make you aware of the website and to highlight the information that is online already.

The Website Today

You don't have to wait until the project has finished to find useful information on the website. If you've found the contents of this newsletter interesting, and think that your organisation might benefit from the final project results, we'd encourage you to learn more by taking a look at the website now – just head off to INDIRES.EU.

While articles in this newsletter provide a fascinating glimpse into some of the work carried out in INDIRES during the first year, the website provides a good overview of the project. In particular, you can read about all the major initiatives including resilient communication, sensor technologies, unmanned vehicles, drilling equipment and roof supports, auxiliary supporting equipment, and simulation. Information is also provided on the work plan we are adopting to ensure that the technical objectives are met. At a broader level you can learn about the rationale for the project and discover something about the types of organisation we expect will benefit from the work. In addition to mines rescue teams, we anticipate that coal producers will benefit because the initiatives will help ensure the future operation of a mine following an incident. Some of the technologies developed will also provide a service for abandoned mine management.

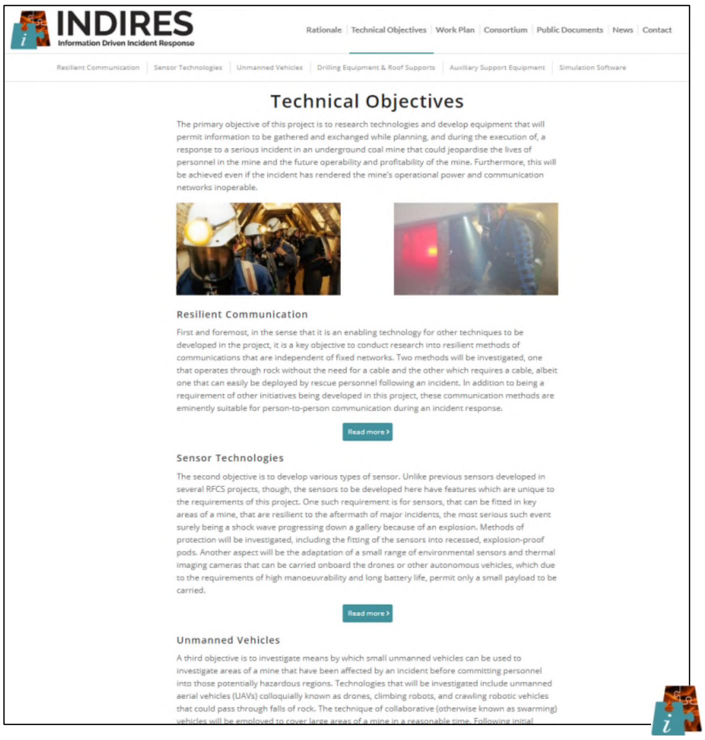
> *"We have created a project website at INDIRES.EU"*

Also, if you are reading this newsletter on paper but you'd like an electronic version so you can print more copies or email it to a colleague, you can download a PDF from the Public Documents section. Please note that, although the project consortium holds the copyright on this newsletter, we do grant you permission to distribute it to interested parties, with the condition that you only distribute it in its entirety.

News Reports

Another important part of the website provides up-to-date news. Here important milestones such as our twice-yearly Partners' Meetings will be reported and, more importantly, to you as a stakeholder, advanced notice of related presentations at conferences, and project workshops for potential end users, will be provided.

We trust that you'll find the information provided on the website interesting and that it will provide you with a glimpse of the project outcomes. We suggest that you keep an eye on the News section of the website so that you know of upcoming events and of preliminary project results.



The PGG Rescue Teams and their Expectations of INDIRES

__Grzegorz Plonka__, of __PGG SA__, introduces this Polish mining company's rescue teams and describes the vital role they play in the safe operation of their coal mines. He also discusses the benefits they are expecting as a result of the INDIRES project, and specifically the lightweight props that are beng produced by project partner GIG.

Introduction

Mine rescue work is a vital part of mining life. Since its inception, mine rescue workers have been bringing help to those injured in accidents and disasters, at all times and under all conditions. As is the case for all underground mines in Poland, the mines belonging to INDIRES project partner PGG SA (Polska Grupa Górnicza SA – Polish Mining Group) have their own mine rescue teams, which comprise approximately 7% of the total personnel of over 32,000 employees.

Rescue Teams

Each of the 14 PGG SA mines has its own on-site mine rescue station, equipped with all the instruments and tools necessary to conduct rescue operations. At least two rescue teams, comprising ten rescue workers, are on active duty every day in the underground workings of each mine during each shift. This means they are ready to bring help at any moment in case of an emergency. In total, there are 116 rescue teams employed daily at PGG SA, equipped with Faser W-70 or Dräger BG-4 plus breathing apparatus.

For their everyday duties, rescue teams are usually tasked with work related to fire and methane prevention, such as constructing explosion proof stoppings or sealing the rock mass with chemical and mineral agents, all the while remaining in contact with the mine dispatcher should the need to bring help arise.

Periodic Training in Chamber

With regard to preventive actions, the mines organise periodic drills simulating rescue operation conditions. Each rescue station is equipped with a special training chamber which is an obstacle course simulating various underground conditions such as. low and tight passages or low visibility.

On-site mine rescue units work in cooperation with a professional unit, the Central Mine Rescue Station in Bytom, through its field units – the District Mine Rescue Stations in Zabrze, Wodzisław Śląski and Jaworzno. Here, mines delegate their rescue workers as part of their mandatory active duty. These units also conduct cyclic courses, fitness tests and exercises verifying the competence of the rescue workers.

Furthermore, three PGG SA mines also employ specialist climber rescue teams, trained and adapted for conducting rescue operations using mountaineering techniques. Such teams are called in during rescue operations in rising headings. Members of these teams are taught at special courses and trained in mountainous areas and caves.

Mining Conditions

PGG SA mines operate under difficult mining conditions, at depths reaching up to 1200m and in increasingly hazardous environments. The mines are prone to rock bursts, methane, microclimates and spontaneous fire occurrences. Operating under such conditions requires the utilisation of the highest safety standards as well as periodic drills, testing the readiness of the rescue workers to conduct rescue operations.

Among the difficult duties that rescue workers need to perform during their service, and especially during operations involving lifesaving, are tasks such as cave-in rescue operations. During such operations, the problem is not only an

Mines Rescue Team – Jankowice Mine, 1951

Rescue Team with Faser W-70 Breathing Apparatus

Rescue Roof Supports in Training Chamber

atmosphere that is unfit to breathe, but also the sizes of the workings and the time required to reach the injured. When embarking on cave-in rescue operations, rescue workers often have to struggle with tons of rock mixed with the steel structures of machines and supports, where driving a rescue drift requires strength and determination.

Each metre of the drift is paid for with hard work, usually manual and non-automated, with tons of rock and other material being dug and transported. The difficulties posed by cave-in rescue operations have been demonstrated in full during the recent operations in the Wujek Ruch Śląsk and Zofiówka Mines.

Specialist Equipment

In addition to the standard equipment used by rescue workers, such as gear that allows them to operate in atmospheres which are unfit to breathe (self-contained breathing apparatus), during operations following a cave-in, the rescue workers also need to be equipped with equipment for safe movement through caved-in rubble. Included here is Holmatro cave-in equipment, comprising cutting tools, air cushions and special support elements. Such equipment – especially rescue roof supports – is heavy, which, considering the necessity to carry it manually, hinders the progress of rescue operations.

PGG Climber Rescue Team Member

INDIRES Contribution

The difficult conditions that mine rescue workers need to face served to inspire the creation of the INDIRES project. In addition to the project's important communication aspects, it also work into developing better and lighter equipment for conducting rescue operations.

Conventional steel props, as used for additional reinforcement in cases of roof falls and primary support in irregularly shaped galleries, have a relatively high load bearing capacity. However, they can weight from 90kg to 200kg, depending on their construction, height and load bearing capacity. This weight is considered a major drawback for rescue use such as supporting temporarily drilled tunnels, so a new construction of prop will be developed by project partner GIG. This will provide a favourable combination of strength and low weight, for ease of transportation by rescuers. In particular, steel will be substituted by modern composite materials. Such composites can provide sufficient strength while also being non-combustible. This is an important consideration in this application.

Photos from an Underground Rescue Operation

Partners' Meetings – Ensuring Effective Collaboration

We report on our first two INDIRES partners' meetings which took place in South Wales and Poland during the first year of the project.

Effective collaboration in research is only possible by good communication. To ensure this, representatives of each partner organisation meet together on a regular basis to discuss progress and our plans for the future. Two such partners' meetings took place during the first year of INDIRES.

September 2018, South Wales

INDIRES partners got together for the first time for the project kick-off meeting, which was held in the former coal mining area of the Rhondda Valley in South Wales, UK.

On Tuesday 19th September 2017, representatives of the consortium each gave presentations, introducing their organisation and outlining the research work they will carry out during the three years of the project.

On 20th September we had a visit to the Mines Rescue Station at Dinas, which is operated by MRS Training & Rescue. Operations Manager Mark Tibbott gave a presentation covering the history of mines rescue in the UK generally, and South Wales in particular. Following this, Mark led a tour of the rescue station's facilities, that are used both for operational purposes and for rescue-related training. We are grateful to Mark and MRS Training & Rescue for providing this valuable insight into an area that is central to the INDIRES project.

Finally, we had a fascinating visit to the Rhondda Heritage Park, which is a coal mining museum based around the former Lewis Merthyr Colliery which operated from 1850 to 1983. Our guide, Graham, described the dreadful working condition in the mine's early days and spelled out the scale of mining disasters in South Wales.

The explosion at the Senghenydd Colliery in which 439 miners were killed is well known. Perhaps a more chilling statistic is that, in the late 19th century, a miner was killed every six hours in the UK.

While the mining industry can take comfort from the fact that such statistics are a thing of the past, there is no place for complacency and we hope and expect that the INDIRES project will further reduce the adverse impact of mining on the lives of those who work underground.

April 2019, Poland

KOMAG and SUT hosted our second Partners' Meeting in Gliwice, Poland, on 18th and 19th April 2018.

During the first day, each of the partner organisations gave a presentation on the research they'd conducted during the first nine months of the INDIRES project. It was encouraging to see the significant amount of progress that has been made so far and the collaboration between partners, both of which give us confidence that a very successful outcome will be achieved. The first day concluded with a discussion of organisational issues.

The second day started with a presentation about their organisation by project partner the Silesian University of Technology. This was followed by a tour of their laboratory and workshop facilities.

In the afternoon, partners were taken to a nearby museum based around a former mine. In a change from coal mining, however, the mine at Tarnowskie Góry had been a major producer of silver, lead and zinc. A closing ceremony was held at KOMAG's offices.

Next Meeting

For our next meeting, we will be guests of Premogovnik Velenje, the Velenje Coal Mine in Slovenia. We will report on this meeting in our next newsletter.

Resilient Communications: Maintaining Information Flow

***David Gibson** and **Mike Bedford**, of the **University of Exeter**, explain the particular challenges of underground communications and how they are being met, both to provide person-to-person communication and as an enabling technology for other initiatives in INDIRES.*

The Challenge

As a worst case scenario, it has to be assumed that a serious mining incident – such as a fall of rock, fire or explosion – will destroy the mine's permanent power and communication networks. So, while the flow of information is key to the rescue response to that incident, it is highly likely that the normal channels of communication will not be available to assist the rescue operation. For this reason, resilient communication is a key theme of INDIRES. Such methods of communication should not rely on any of the mine's fixed infrastructure and should, therefore, either work without wires or utilise a wire laid by a rescue team as part of their operation. Both these options are being researched.

Applications

The requirement for resilient and effective communication during a rescue response might be self-evident but there is more to this than meets the eye.

Certainly, a crucial application of any such technology is to allow person-to-person verbal and perhaps textual communication, to coordinate rescue operations. We can imagine such exchanges taking place between members of the rescue team underground, and also with a controller on the surface. It is also possible that this could be extended to miners who have been affected by the incident. However, other technologies being developed in this project require a communication capability that could be met by resilient radio techniques.

Monitoring conditions in the mine is an important aspect of many rescue activities because allowing rescue personnel to enter mine workings, with no knowledge of the environmental conditions, poses a severe risk to those rescuers. However, as with fixed communications equipment, it is possible that incidents such as fires and explosions will have destroyed the sensor networks that are present in mines to provide a normal operational service.

For this reason, an element of research within INDIRES is the development of novel sensors, that will survive a serious incident, and can be deployed afterwards for use in the rescue response. It is also possible that such sensor units could be fitted with microphones or other means of detecting the presence of personnel, for example, miners who have been trapped as a result of the incident.

The rationale being adopted involves recessing these resilient sensor assemblies into holes drilled gallery roof so that they will withstand a blast passing down the gallery, and would also be protected against fire and water. Various methods are being considered for releasing the sensor from its recess in the aftermath of the incident. The sensors will be battery powered so that it is not reliant on the mine's vulnerable power network. In the same way, however, the sensor device cannot be reliant on the mine's wired communication system. As such, it will require access to a wireless communication system as described here.

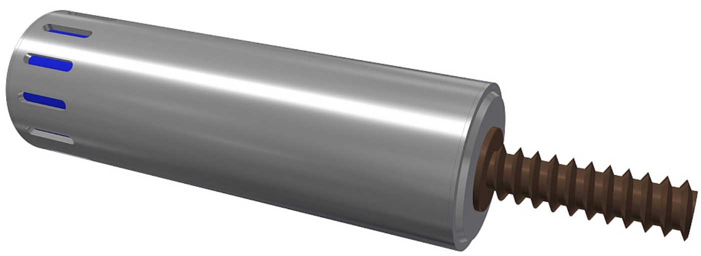
Another strand of INDIRES research is into unmanned robotic vehicles that are able to enter hazardous areas of the mine in the early stages of a rescue response. Some of these vehicles will be small enough to pass through falls of rock before tunnels could be drilled to allow access by rescue personnel. Like the roof-mounted resilient sensors, they will also play an important role in monitoring conditions before making a decision to sent rescuers into an affected part of the mine An article on page 14 of this newsletter describes the work on this technology in more detail. Such robotic vehicles will be reliant on radio communications and so they are another potential beneficiary of the technologies described here.

Two Approaches

Within the project there are two strands of work on radio communication; one covering wireless radio and one covering wire-guided radio.

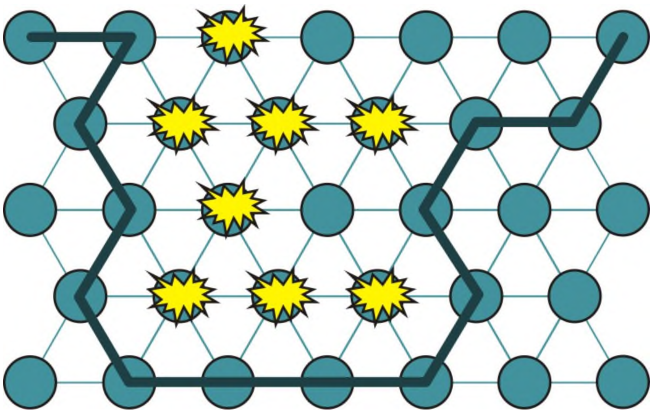
Wireless Radio

'Normal' wireless radio is usually thought of as a flow of electromagnetic radiation. At high frequencies, the radiation can travel along mine passages, but is rapidly attenuated if we try to make it travel through a conducting medium such as rock. Lower frequencies are attenuated less, and sufficiently low-frequency radio can penetrate rock to a useful extent. Interestingly, low frequencies can also travel for some distance along mine passages if the geological conditions are favourable, although this cannot be guaranteed.



Resilient, survivable sensor units, recessed into the gallery roof, will require wireless communication capabilities.

Reconnaissance robots, deployed in the early stages of the response, will need wireless communications.



Mesh networks are resilient to node failure.

Unlike previous wired-guided rescue radios, the one being developed in INDIRES works without close proximity to the wire.

Low frequency (LF) radio at, say, 30–300 kHz, is used for through-rock communication by mine operators in some geographical areas. However, the required power can increase very significantly with distance so, to achieve a practical range, these systems can be very expensive, requiring huge surface antennas and very high powers. They also tend to operate only from the surface to underground or, where two-way communication is possible, the underground equipment is too large to be considered truly portable.

The solution being adopted in INDIRES is to design equipment capable of working as part of a mesh network. In such a mesh network, LF/VLF radios are placed at regular intervals within the mine and communication is achieved by each station forwarding data to the next station. With such an arrangement, the power requirement increases only by the number of nodes transmitting instead of a much larger factor for a single link.

In addition, a mesh network is resilient to equipment failure in a way that a single link is not. This is because, in the event that one or more nodes is damaged – always a possibility following a serious mining incident – a different path can be established as shown in the diagram at the top of this page. In this particular example, the normal route from the top-left to the top-right is through the intermediate five nodes shown in a horizontal line. However, in this diagram, we are assuming that the group of nodes identified with the yellow starburst symbols have failed, thereby interrupting the normal route. Under these conditions, the self-healing nature of a mesh network establishes the new route shown.

Wire-guided Radio

Although an LF/VLF mesh network offers an ideal solution because it operates without wires, it must be recognised that it will rarely be economically viable to 'flood' a mine with mesh nodes so not all areas will be covered. Research is, therefore, being conducted into a novel method by which hand-held radios can be used in mine galleries over considerable distances, around bends and in the presence of partial collapses caused by a serious incident. The technique uses a wire to guide a radio signal along the galleries but it differs from the rescue communication system developed in the previous RFCS RAINOW project, in which either the handset had to be clipped loosely onto the wire, or else a relay station had to be placed in close proximity to the wire thereby allowing the handset to communicate via Bluetooth. When used by rescue personnel, removing this restriction will allow communication to be more immediate and less distracting from other tasks. Potentially it could also be used for communication with flying drones which, by definition, cannot be tethered to a wired communication line, although LF/VLF mesh technology will probably be used for this purpose in this project.

The new technique is similar to that of leaky feeder communications that is often used as part of the fixed communication infrastructure in mines and transport tunnels. However, while a leaky feeder is a bulky coaxial cable that would not be suitable for rapid and temporary installation by rescue personnel, the system envisaged here would use a much smaller diameter, lighter and cheaper line that can be laid quickly and easily. The technique is to build on the methods of monofilar and bifilar radio communication that preceded the development of leaky feeder systems, and research into which was largely curtailed once leaky feeder technology was established. Monofilar systems, which can use a thin single or dual conductor cable, allow good coupling to a radio anywhere within a tunnel's cross section but suffer high levels of longitudinal attenuation because of leakage to the tunnel wall. Bifilar systems, on the other hand, which require a thin two-conductor cable, do not couple as well to radio handsets that are not in close proximity, but have a lower level of longitudinal attenuation. Research will be conducted into a hybrid system that capitalises on the strengths of monofilar and bifilar mode systems by employing periodic or continuous conversions between the monofilar and bifilar modes along the length of the cable.

A Study of Radio Communication

As we complete this newsletter, work has just started on the wire-guided radio, as required by the project plan. We shall report on our progress in the next newsletter. Here we report on the through-rock aspect of the INDIRES work.

Electrical Noise

A necessary aspect of our study into antennas and propagation is to collect data on electrical background noise underground. However, an analysis of the methodology for undertaking this task has lead us to draw the conclusion that it would be more practical to do this work *after* our early prototype equipment has been developed. The results will then be used for further development of the equipment, later in the project.

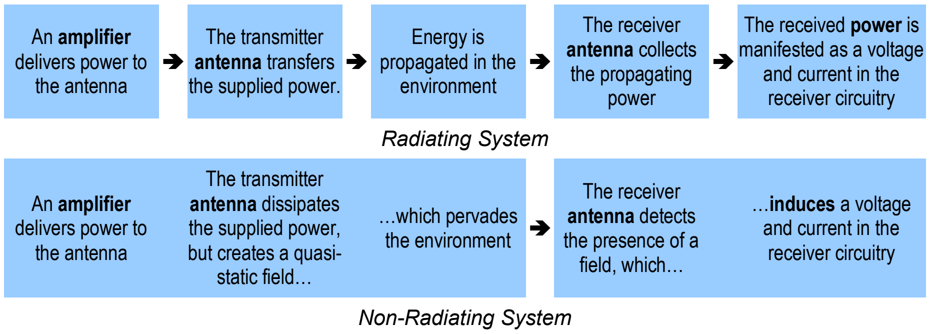
Propagation

Our study of propagation began by noting that, contrary to the simple statement, above, that wireless radio is usually thought of as a flow of electromagnetic radiation, this is not true for operation closer than a wavelength from the transmitting antenna – and in a conducting medium, the wavelength of the radio signal is shorter than it is in air. For example, at

100kHz the wavelength in rock could be as low as 100m, instead of its value in air of 3000m. We can identify several regions within the field, which we refer to as the **quasi-static** zone, the **near-field** zone, the **transition** zone and, eventually, the **far-field** or **radiation field** zone.

The term 'propagation' refers to the flow of energy. For near-field and quasi-static operation there is no net flow of energy away from the source, so there is no propagation 'as such'. What we therefore mean by propagation is debatable, but is probably '*the pervading of the ether by quasi-static fields*'. This may seem to be a pedantic point but its significance is that the design principles are different to that of 'true' radio.

In a radiating system, our aim is to maximise the end-to-end transfer of power. However, because there is no power transfer in a near-field system, we can expect the design principles to be different. In a radiating system the antenna is designed to have a power-transfer efficiency that is as close to 100% as we can manage; whereas, in a near-field system, the antenna has an efficiency of 0% – i.e. the incoming power is dissipated as heat.



In a non-radiating system the antenna parameters cannot be considered in isolation from the environmental parameters, so a system analysis is more complicated

The essential differences between a radiating and non-radiating system are shown in the diagram, above.

One easy way to study the behaviour of the fields is to use a finite element analysis. However, that only models a particular situation and does not allow us to generalise. An exact theoretical analysis can include features such as layered rock, but it is extremely complicated. Thus, the approach so far in this project has been to approximate the field equations to something that, whilst giving a 'wrong' answer, produces results that are easier to generalise and to compare. For example, we can draw comparisons between electric and magnetic antennas, which is not possible to do otherwise, except for specific cases. Those comparisons might be inexact, but are probably not too wrong to be of use.

Antennas

The table, below, outlines the types of antenna that we are studying. As noted above, in a near-field system the antenna parameters cannot be considered in isolation from the environmental parameters, which makes the study of antennas and propagation rather more difficult than for 'true' radio. Additionally, the receiving

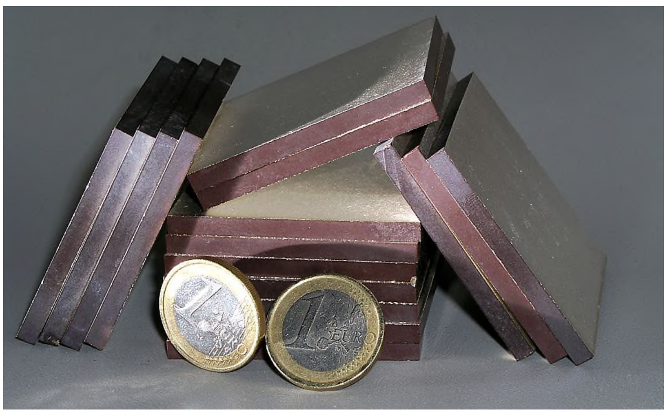
Magnetic Sources:		**Model:** Magnetic dipole antenna. **Near field lines:** Bar magnet; inverse cube law		
Description	**Characteristics of Antenna**	**Points to Note**	**Transmitter Usage**	**Receiver Usage**
Air-cored loop	The loop needs to be large, and flat – spirals have useful characteristics	The number of turns has no effect on performance; but too few turns implies high I^2R losses; whilst too many turns implies self-resonance, self-leakage and proximity effect problems. The system can be mathematically modelled to determine a figure of merit (specific aperture)	Normally used tuned, but can be used un-tuned for wideband applications, provided driver is designed with this in mind. (Class B drivers will not work).	Normally used tuned, but can be used un-tuned for wideband applications
Ferrite-cored solenoid and bobbin	The rod needs to be long and very thin for best performance. Bobbins have useful characteristics		Difficult to use well because of a potentially high Q-factor.	Difficult to noise-match if it is un-tuned
Special Materials	Amorphous metal may give a high performance at very low frequency		Difficult to use well because of a potentially high Q-factor.	Difficult to noise-match if it is un-tuned
Electric Sources:		**Model:** Electric dipole antenna (generates magnetic field). **Near field lines:** Concentric circles; inverse square law		
Description	**Characteristics of Antenna**	**Points to Note**	**Transmitter Usage**	**Receiver Usage**
Grounded Dipole	The antenna wires are grounded at the ends, so the power dissipation depends on the conductivity of the medium	The performance depends on the medium more than antenna, so a figure of merit is difficult to determine	Normally used un-tuned	Normally used un-tuned; wide-band. Usage of this antenna as a receiver is 'erroneous''. It is better to use a magnetic dipole as a receiver.
Ceramic tile	Small tiles of high-K material	Can be analysed to determine a figure of merit (specific aperture) in a similar fashion to loop antennas	Difficult to use well because of a potentially high Q-factor.	Not intended for use as a receiver
Anapoles	Toroidal antennas, air-cored or ferrite –cored	Essentially, these synthesise an electric dipole. It is doubtful whether they will be of use here, but they are of interest in other underground applications e.g. radio-location.	May not be very efficient without a ferrite core; but that will result in a large Q-factor	Not intended for use as a receiver
Transmission Line Sources:		**Model:** TEM transmission line. **Near field lines:** TEM field lines; exponential attn causes skin depth-like effects		
Description	**Characteristics of Antenna**	**Points to Note**	**Transmitter Usage**	**Receiver Usage**
Transmission Lines	The signal is launched into a coal-seam transmission line, either via a suitably orientated antenna or via grounded electrodes	In-seam propagation can be low-loss and may occur as a result of natural coupling of the signal – or we could specifically design for this situation.	Wide-band	Not intended for use as a receiver

antenna may need to be a different design to the transmitting antenna.

We are interested in the magnetic part of the electromagnetic wave, because the electric part can be significantly attenuated in a conducting medium, and because electric fields are difficult to handle with small antennas. However, this does not limit us to the conventional magnetic induction loop antenna, because electric field antennas do, of course, generate a magnetic field. (A tricky question to ask engineering students is why an electric current flowing in a wire generates a magnetic field and not an electric field).

The magnetic quasi-static near-field from a magnetic dipole falls off with the inverse cube of distance, whereas the same field from an electric dipole falls off with inverse *square* of distance. So, in some situations, an electric antenna can transmit a magnetic field that is strong enough to be useful, but this depends on the allowable size of the antenna, the field distance and the method of driving the antenna. This dilemma requires a careful study, which is still ongoing within the project.

It is likely that we will choose to use a conventional loop or ferrite rod antenna but there are some interesting variations, as noted in the table on the previous page. Firstly, the performance of a ferrite rod can be increased by adding ferrite plates to the ends of the rod, turning it into a bobbin. For a transmitting antenna, the best shape is short and fat, whereas for a receiver, a rod should ideally be long and very thin. The problem with an electric wire antenna is that, at low frequencies, it is difficult to force the current to flow to the ends of the antenna. The grounded electric dipole avoids that problem; another solution is to 'anchor' the current at the ends by using plates separated by a dielectric – like a capacitor. This type of antenna was studied in RFCS project ADEMA, but was found to be expensive and difficult to drive. We are investigating whether the performance can be improved.



Small high dielectric-strength tiles can be used to construct a type of electric dipole antenna

The Mesh Network

Once the antenna and propagation issues have been resolved we have to consider how the nodes will be linked to form a mesh network.

A conventional mesh network operates by transmitting a packet of data from one node to another, sequentially. Thus, the overall data transfer speed (or bandwidth) is given by dividing the intrinsic bandwidth by the number of nodes. For our low-frequency system, we cannot afford this large latency, so we are investigating the use of multi-channel communications, where a node will start to retransmit the data packet whilst it is still being received. This, however, raises questions on how error detection and correction are applied. Alternatively, if our investigation of antennas and propagation leads us to choose a near-field rather than a transition-zone system, then we can make use of the extreme localisation of the transmissions. This work is ongoing within the project.

Protocols for packet data transmission on the Internet are well established, and generally operate using what is known as the *four-layer DARPA model*, or *Internet Protocol Suite*. However, our network is not attached to the Internet (except, perhaps, at some specified gateway) so we are free to re-specify its operation to suit our requirements. Our ideas are still being discussed and evaluated, but are likely to cover the following points.

1. Because of the need to prevent interference between adjacent nodes, we might use multiple channels. We might also use different modulation schemes; perhaps a robust DQPSK modulation at low speed and a different scheme for higher-rate data.
2. One of the salient points of Internet networks is that the error rate is low, so error checking and correction does not need to take place at a low layer in the model. However, our network is likely to behave significantly differently, such that we might want to perform an *acknowledge / resend* operation at packet level. But this is to be determined.
3. A less rigid structure to the datagram packets may be advantageous during development and debugging. Possibly we will want to use human-readable data rather than just a stream of bytes. The fact that our development units might, therefore, need a higher bandwidth might mean that we need the nodes to be more closely spaced than they would be in an actual application.
4. We will probably *not* make use of IP addresses within our layer model. At a local level, in Internet systems, packets are delivered using unique MAC addresses and our system will use that concept.

The Raspberry Pi Computer

The Raspberry Pi (**raspberrypi.org**) is a UK-manufactured personal computer, which could be described as what would be left over if one were to dismantle a laptop and remove the screen, keyboard and hard-drive (and add some general purpose i/o ports). They cost about €40 and run from a 5V power supply. If user input is required, a USB keyboard and mouse can be added. Video output is via an HDMI cable. For this application we will interface the devices via an Ethernet cable and a network switch. The devices also have built-in WiFi and Bluetooth. The operating system is a GUI-based version of Linux.

The picture shows the Raspberry Pi 3 Model B. It features a 1.2GHz QUAD Core Broadcom BCM2837 64bit ARMv8 processor, BCM43438 WiFi on board, Bluetooth Low Energy (BLE) on board, 1GB RAM, 4xUSB 2 ports, 40 pin extended GPIO, HDMI and RCA video output.

Our initial work in this task has concentrated on building a development system that can emulate the routing algorithms that are needed. Although this could easily be done in a number of software packages, we have chosen to model the network, with some degree of verisimilitude, using a separate microcomputer for each node. We are using a network of Raspberry Pi devices (see box above), each of which runs standard web server and web client software. Clearly, the devices use standard Internet protocols to communicate, and our mesh network emulation is merely an application-level routine. The advantage is that we can develop our layer protocols in a well-understood development environment using standard web tools – HTML, Javascript and PHP – and have the development network accessible over the Internet to other partners in the project.

Skupina hse
PREMOGOVNIK
VELENJE

GIG

UNIVERSITY OF
EXETER

GEOCONTROL

DMT

KOMAG

emag®
INSTYTUT BADAWCZY

POLSKA GRUPA
GÓRNICZA

SILESIAN UNIVERSITY
OF TECHNOLOGY

uc3m
Universidad
Carlos III
de Madrid