STATE OF THE ART IN LONGWALL AUTOMATION

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ABSTRACT

Inertial navigation technology has, for the first time, allowed the position of a longwall shearer to be mapped in three dimensions. Following the success of the technology in highwall mining and the successful trials on a longwall face, the Australian Coal Association Research Program (ACARP) commissioned a three year "Landmark" project with the goal of advancing longwall automation to the level of "on-face observation" by the end of 2004. Project outcomes were divided into ten areas, the first of which, automatic face alignment, was successfully demonstrated in a series of underground demonstrations concluding in late 2004. The project has had the support of major longwall equipment manufacturers including Eickhoff, DBT and Joy Mining Machinery. The Landmark project has recently been completed and this paper describes progress achieved in all ten areas including horizon control, a new information system using 3D visualization, and in the area of reliability and maintenance management and machine condition monitoring. Planned extensions to the Landmark Project are discussed.

INTRODUCTION

There have been problems with previous attempts at longwall automation. Automation systems have worked only in ideal conditions. As soon as problems or "exceptions" occur on the face, operators tend to revert to manual operation and the automation technology is discarded. Even if the automation technology does work in good conditions, unless it produces as much coal as manual operation it is not used. Moreover the lack of suitable sensor technology has meant true closed-loop automation of extraction systems on a production basis has not been achievable.

There have been two major inputs to the automation process from Industry.

- Since the longwall is the prime profit centre, a high level of production consistency rather than manning reduction should be the focus of automation.
- Automation should be directed towards the removal of persons from exposure to respirable dust. Even with advanced dust control techniques, most high production faces are finding statutory standards difficult to achieve.

The Landmark Project has introduced new sensors, particularly a new shearer position measurement system, to the longwall automation problem. It has approached the introduction of automation systems in a systematic way , by first addressing reliable automation of face systems in normal operation and providing for a complementary way of handling exceptions. This has resulted in the concept of 'on-face observation' in which face equipment is fully automated, but local operators manage exception conditions such as face guttering and mechanical failures. It has been found during the project that this outcome is significant and in many cases it may be all that operators require. It is also on the direct path to full automation.

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Specific attention has been given to equipment reliability in order to generate new maintenance paradigms for equipment operation in the automated environment.

PROJECT AIMS AND OUTCOMES

A number of separate but related research areas were identified covering specific technology development, integration of system components and attention to the way automation outcomes are introduced to the industry. The ten specific outcome areas were:

- Face alignment
- Horizon control
- Open communications (between OEM and external systems)
- Longwall equipment manufacturers (OEM) involvement and commitment
- Information systems
- Components to enhance production consistency and reliability to minimise production risks in an automated environment
- Redefined functions of face operators and training
- Minesite trials and demonstrations
- Acceptable commercialisation plan
- Implementation plan for progressive automation

The paper will briefly summarise all outcome areas and results obtained in the project.

Face Alignment

This area of work concentrated on the geometry of the face within the gate roads. The two project goals were:

- to automatically measure the actual 3D position of the entire longwall face by measuring the position of the shearer as it traverses the armoured face conveyor (AFC).
- to use this information in a closed loop to control the movement of the powered supports and use this information to adjust the face geometry to a desired shape.

This technology had been applied extensively to highwall mining guidance (Reid 1997) and also in a successful trial on a longwall face at South Bulga (Reid 2001).

Automatic measurement of shearer position using the Landmark Shearer Position Measurement System (SPMS) has been achieved on a production basis. Accurate shearer position information is now routinely used at Beltana No 1 mine.

Supervised operation of closed loop face alignment has been realized. Automatic measurement of creep distance has been demonstrated and creep correction information has been manually applied to the face at Beltana. A system to automatically measure longwall retreat progress has been prototyped and tested.

In further development, production trials will optimise sensor and software performance.

Figure 1 shows 3D position data that has been received from the shearer using a wireless Ethernet-based communications system developed as part of Outcome 3 of the project. Software applications have been written to enable on-line shearer position to be accessed remotely over the internet.

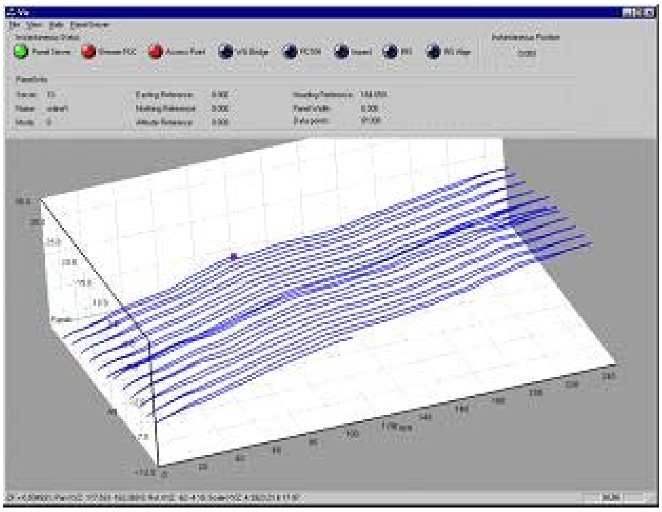

Figure 1: Three dimensional view of actual shearer position

Horizon Control

This outcome involved maintenance of the cutting operation between desired roof and floor horizons. The goal was to provide automatic horizon control responding to actual changes in seam profile. The major project development has been the introduction of the concept of an integrated ‘cut model’ which generates the real-time roof and floor horizon trajectories for each shearer run (Figure 2)and is able to accept inputs from various sources:

- The base input uses the vertical shearer position information available from the SPMS. The current floor horizon is derived by extrapolating the floor profiles of a number of previous shears.
- Outputs from real-time coal interface detection (CID) systems can be used to provide inputs to the cut model to enhance the predicted floor profile for subsequent shears.
- On-line inputs from operators to modify the horizon parameters.

As well as the cut model, a ‘seam’ model to predict seam geometry based on historical information such as borehole and seismic exploration has been developed. In general the resolution is too coarse for the seam model to be used for real-time equipment control. Instead the seam model is used to place bounds on the horizons predicted by the cut model. When predicted horizons intersect the seam boundaries suggested by the seam model, warnings are generated to check the cut model for validity, usually by on-face observation.

A ‘controlled traversing cut’ model has been generated to enable effective horizon control through fault conditions. This requires high-resolution 3D modelling data for the mining area in question to allow for input to the controlled traversing cut process.

Sensor development for CID’s has concentrated on two areas:

- Heating of strata and picks. When hard roof strata are encountered, picks and the roof itself are heated. A small thermal camera was mounted on the shearer and successfully identified the cutting horizon in real time.
- Optical detection of marker bands. One of the most common horizon control techniques used by shearer drivers is based on the use of visual markers in the seam profile. Underground trials have shown that marker bands can be automatically detected.

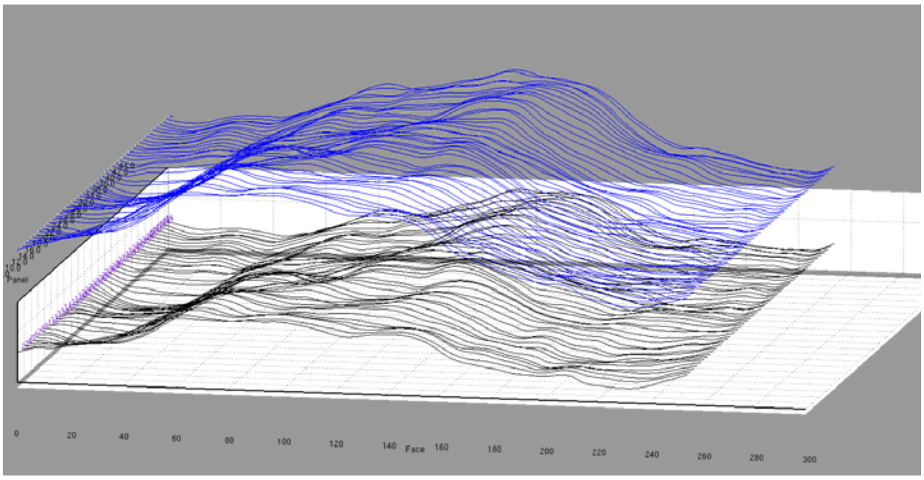

Figure 2: Cut model extracted roof and floor surface constructed from real SPMS data.

Communications and Operator Interface

An early project requirement was the development of a communications method to facilitate the flow of information between landmark-developed sensors and systems and longwall system elements sourced from various manufacturers, especially from the shearer to the maingate. The introduction of the Ethernet/IP open-system communication standard and associated development of the Landmark device and control system specifications have been fundamental to the overall success of the project. This has provided a solid platform for ongoing development and acceptance of an open industry-wide (non-OEM specific) standard for the interconnection of mining equipment.

The wireless Ethernet (IEEE Standard 803.11b) communications link to the shearer has been one of the major successes of the project. Along-face coverage has been very reliable and the link is now an established part of the mine's production system.

Other broadband shearer-based services such as video and intelligent sensor data are being introduced and a redundant shearer-maingate communications system based on broadband power line carrier technology is under development, with initial trials showing promising results.

This outcome also has wider implications for open connection between equipment in the coal mining industry. Mine operators and equipment specifiers are able to synthesize a system confidently using products from various suppliers.

To ensure that there are no compromises in the OEMs' duty of care obligations the landmark process controller only gives recommendations to the OEM systems rather than commands and are in turn filtered by the OEM's internal safety mechanisms. If motion inputs received by a system cannot be implemented because they are outside the safe working envelope, the system does not actuate and reports that the motion cannot be achieved. Consequently, safety is maintained.

OEM Involvement

This is a key outcome for the success of the project. Manufacturers of longwall equipment have needed to be directly involved in the Landmark process to enable technical outcomes to be incorporated into future machine specifications. In order to achieve this, clear communication of project goals to OEMs has been an ongoing project activity, key contacts within their organisations have been made and mutual R&D linkages are ongoing. This has resulted in a high level of cooperation from the OEM's, essential both for the project and ongoing commercialisation activities.

Information Systems

The Information System outcome evolved significantly during the project. The initial implementation has clearly shown that relevant forms of information can be made available to different people at different locations at the mine site and appropriate interaction with the system can occur from various locations including on the surface and at the maingate. As the project progressed it became clear that that a high quality 3D visualisation of actual face equipment and conditions will be essential to give users monitoring the system remotely confidence that the automation system is operating correctly

Visualisation systems incorporating database and graphical user interface software, depicted in Figure 3, to allow multiple users access to tailored information have been developed and an integrated information system to merge automation, geotechnical, mine design and equipment performance has been put in place.

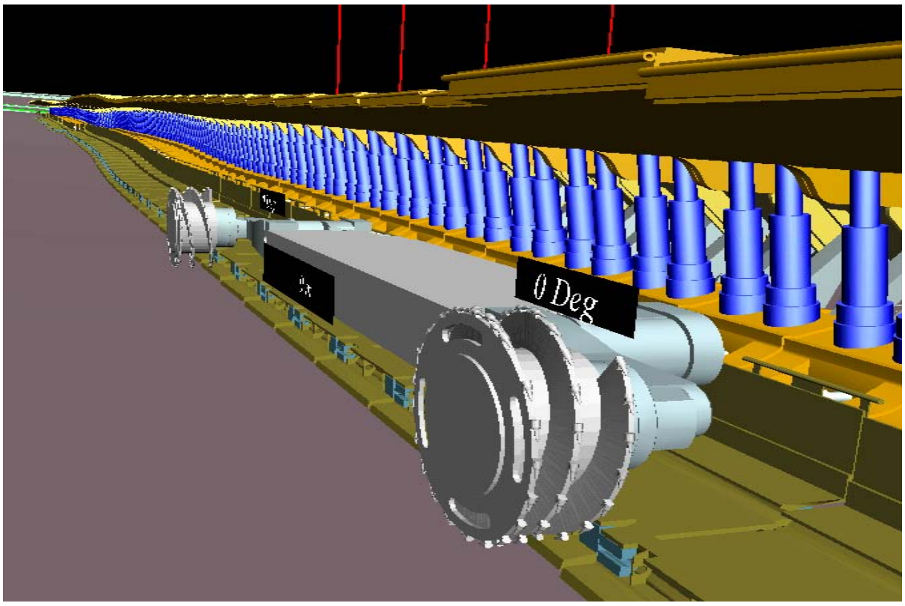

Figure 3: Longwall visualisation

Components to enhance production consistency and reliability in an automated environment

Many of the functions carried out by on-face personnel involve sensing and observation activities that are challenging to automate completely. Consequently the concept of on-face monitoring of the operation of automation systems by personnel either on or close to the face was adopted for the duration of the Landmark Project. However the project allowed for several technologies to be developed to proof of concept level to assist these operator observations. A summary of the areas investigated and the results obtained are given below:

Coal Flow Optimisation

Monitoring coal flow through critical areas with video equipment has been shown to be feasible. Millimetre wave radar also shows promise for these applications particularly due to its performance in poor visibility due to dust.

Improved Convergence Monitoring

Experience at several mines highlighted both the advantages of collecting closure data for geotechnical analysis, and the difficulties with installation and unreliability of existing systems. A new tilt meter-based wireless convergence monitoring system which overcomes many of these issues has been prototyped.

Chock Pressure Analysis

3D chock pressure maps were derived from mine information which gave timely and informative feedback to operational and mine design personnel. 3D leg pressure graphs based on chock cycles can in future be made available through the Landmark Information System (LIS)

Void Monitoring Systems

Millimetre wave radar and laser rangefinder systems were found to be the best prospective technologies. The problems involved in suitable mounting arrangements on the shearer will impact on the practicality of their use. The smaller the sensor, the better the chance there is for successful deployment.

Collision Avoidance (shearer to roof supports)

Other work programs have confirmed prospective technologies for distance measurement in the face area. Mounting sensors on the shearer remains a significant problem in dealing with the harsh environment in terms of physical robustness and visibility.

Gateroad Monitoring

Hardware and software have been developed and preliminary testing has been carried out underground to validate a new on-line gateroad convergence monitoring system.

In addition, it was recognised that to achieve improved machine utilisation and production consistency a substantial improvement in machine condition monitoring is required. A major component of the project concentrated on advancement of condition monitoring and reliability technology. Achievements in this area include:

Reliability Analysis

Equipment-related delays were the single major contributor to the total downtime, accounting for over 50% of all lost production time, with the largest component being delays associated with face equipment. These delays are caused by either genuine breakdowns or by erroneous condition-based alarms.

Maintenance Strategies

The project produced ten recommendations regarding improved reliability management and asset utilization.

1. Low utilization – equipment failure is the major cause and must be addressed.
2. Maturity of technology – continuous improvement required in production in maintenance practices

3. Accuracy of data – Better down time recording tools required
4. Role of OEMs – Input required to address reliability through data collection and root cause failure analysis.
5. Accountability – Make minimization of down time equal responsibility of production and engineering departments.
6. Scheduled maintenance – Review and optimise scheduled maintenance function. Otherwise, failure analysis shows breakdown maintenance is as effective.
7. Equipment availability – The equipment availability targets should be based on total calendar time
8. On-line condition monitoring – Continuously monitor critical components at low and high sampling rates where appropriate.
9. Operator feedback – Make operators aware of practices that have undesirable productivity and reliability consequences.
10. Automation – Should be introduced as it will drive systems continuously according to best operating practice.

Fault Detection and Isolation (FDI)

Tools developed in this project were able to correctly detect and isolate (recall) over 90% of target faults with misclassification rates (precision) lower than 20% using on-line trend monitoring data. This is considerably better than the majority of documented performances of FDI systems using real data.

AFC Chain tension measurements

The program was designed to measure the in-situ chain tension under different operating conditions on the Moranbah North Longwall face. By analysing the distribution of chain tension along the face width under different operating conditions, the mechanisms of AFC failure, optimum operation and maintenance strategies can be formulated. Subject to a successful demonstration of the device, the next stage will be to initiate a testing program to measure chain tension in different sites with different equipment and seam conditions.

Shearer Vibration Monitoring

An on-line shearer vibration monitoring system has been operating for several months and large quantities of data are routinely uploaded onto the PC at Beltana mine office every day. This is the first time the site engineers have been able to obtain continuous time-domain vibration data from an operational shearer. The next challenge is to realise the full potential of this large quantity of data in a way to maximise the benefits for the longwall industry.

Training: Redefined Functions of Face Operators

The skills required in an operator of an automated system are different to those presently required on the face. An on-line training system is being set up utilising the monitoring station and a system simulator. Additionally, because system operational data will be available over the minesite LAN, off-line training will also be possible on the surface using on-line information.

Minesite Trials and Demonstrations

The project has provided for field trials and demonstrations of all the developed technologies at one principal location. A protocol was established to facilitate trials of Landmark project outcomes that satisfied the site operational requirements where the test platform for the research program was the main production centre for the mine.

Commercialisation

This activity facilitates the technical transfer and presentation of project outcomes to the industry. Models for manufacture of automation system components and intellectual property arrangements are being developed and at least one product will be available for limited release before the end of 2005.

Implementation Plan for Progressive Automation

All longwall mines in Australia have been benchmarked in order to provide them with detailed information regarding their current automation status and a roadmap outlining steps necessary to achieve various levels of automation utilising Landmark project outcomes.

CONCLUSIONS

The ACARP landmark process has afforded the underground coal industry a significant opportunity to develop and implement cutting edge technologies into a package that will provide an automation capability for longwall operations. The benefit for the industry will be a potentially higher, more consistent production rate and the removal of face workers from more hazardous areas.

At the end of the current project several important milestones have been achieved:

- On-line 3D shearer position information now routinely available.
- Automatic face alignment achieved using an INS-based sensor on the shearer to accurately measure face geometry and feedback signals used to move OEM roof supports
- System for on-line measurement of creep operational, with creep information incorporated into face alignment corrections
- INS-based enhanced horizon control bench-tested with good results obtained in the location of coal-face features for use in thermal infrared-based horizon control
- Broadband communications system to shearer using wireless Ethernet operational on a commercial-product basis
- EtherNet/IP has been adopted as the standard for communications between OEM and Landmark control systems.
- Landmark Information System developed to integrate information from multiple systems and sensors and to provide high quality visualisation and control interfaces.
- Condition monitoring analysis results suggest the feasibility of implementing an on-line trend and condition monitoring system.
- Major longwall OEMs are actively supporting the project and are partnering technical developments

The project is now moving into a consolidation phase to enable outcomes to be brought to a robust standard to enable full commercialisation to occur. Several mines are supporting this extension by purchasing commercial prototypes for their operations. All companies in Australia who are tendering for new or upgraded longwalls are requesting “Landmark Compliance” in their specifications. Automated Face alignment is now a reality and the other outcomes should be realised over the next two years.

ACKNOWLEDGEMENTS

Acknowledgement is made to ACARP and the trial sites, in particular Beltana No 1 Mine for their level of support for the project. Joy Mining Equipment, DBT and Eickhoff are also acknowledged for their cooperation and support.

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