Progress Towards Longwall Automation

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ABSTRACT: Guidance technology proven in highwall mining applications has enabled a new approach for longwall automation for DERDS faces. This inertial navigation technology has, for the first time, allowed the position of the 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 that will advance longwall automation to the level of "on-face observation" by the end of 2004. The project outcomes have been divided into ten areas, the first of which, automatic face alignment, will progress to an underground demonstration in the first quarter of 2004, and has the support of major longwall equipment manufacturers including Eickhoff, DBT and Joy Mining Machinery.

1 INTRODUCTION

Previous attempts at longwall automation and industry use of current automation technology show that automation applications to date have not dealt with exception issues and have paid insufficient recognition to the requirement of operators not to lose productivity through the use of automation. Automation has only worked in ideal conditions. As soon as problems or "exceptions" occur on the face, operators 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. Operators consistently expressed the view that since the longwall is the prime profit centre, a high level of production consistency rather than manning reduction should be the focus of automation. A second focus expressed should be 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.

Moreover, the achievement of sustained full-face automation in all conditions requires the development of new, complex sensors to monitor the face environment before the removal of human operators from the hazardous face area becomes a possibility. This is in addition to the technical development still required for automation of basic coal cutting sequences under the most ideal conditions. Budgetary constraints meant that simultaneous development of all necessary sensors and equipment automation systems was unfeasible in the Landmark project. Consequently, in order to produce short-term project outcomes, a reduced option of 'on-face observation' was adopted as the basis of the final format of the three-year project. Within this scope, face equipment is fully automated, but local operator input is available to efficiently manage exception conditions. Typical exceptions include geotechnical issues on the face such as face guttering and mechanical issues such as broken rams. However, 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.

2 PROJECT AIMS AND OUTCOMES

Based on the principle of automation with on-face monitoring, a number of separate but related research areas were identified in which project effort in the three-year Australian Coal Association Research Program (ACARP) Landmark project would be concentrated to achieve the goal of longwall automation with on-face monitoring. These areas cover specific technology development, integration of system components and attention to the way automation outcomes are introduced to the industry. The ten specific outcome areas are:

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

The paper will briefly summarise all the outcome areas and results obtained in the first two years of the project. Work in this period has concentrated on the outcomes directly leading to automation of basic equipment functions including face alignment, horizon control, open communications, information system and condition monitoring and reliability. Results in these areas including the real-time mapping of 3D shearer position, on-shearer Ethernet communications, condition monitoring and failure analysis will be reported.

2.1 *Face Alignment*

This area of work concentrates on the geometry of the face within the gate roads. The goals are:

- Automatically maintain face geometry by measuring the actual 3D position of the shearer in space using an inertial navigation system (INS)
- Use that information to control the movement of the powered supports. This ability has eluded previous researchers.

This technology has been applied extensively to highwall mining guidance (Reid 1997) and also in a successful trial implementation on a longwall face at South Bulga (Reid 2001). This outcome area has supplied the first deliverables of the project and is a relatively low-risk outcome. The various technology components, particularly those already present on OEM equipment, are in advanced states of development.

Work to date has concentrated on:

– Development of a real-time shearer position measurement and display system (SPMDS) to provide accurate measurement of actual shearer position in space in real time for display on the surface. This system also provides for logging of shearer position for later analysis. This is a stand-alone outcome on which the remainder of the automation system will be built.

– Enhance shearer initiation of shield advance (SISA) to move chocks to the exact geometry determined by the INS. At this stage of the project, the shearer is controlled manually in the customary fashion.

– Development of novel sensors to implement automatic creep control and tailgate offset (lead or lag).

At the time of writing, an INS has been operating on a shearer in four consecutive extraction panels. 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.

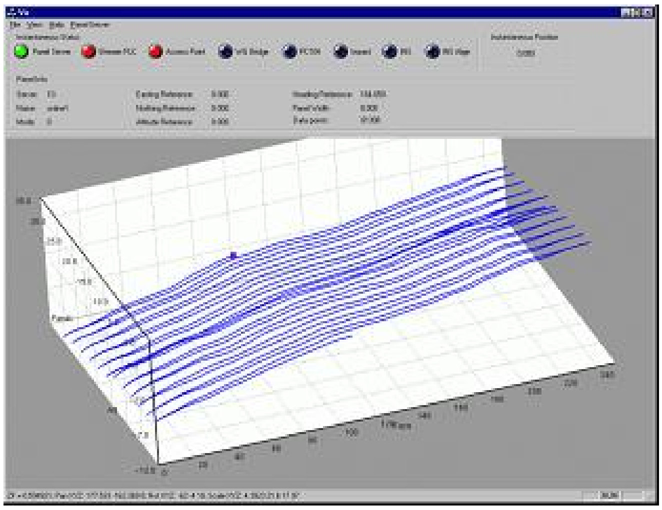

Figure 1 Three dimensional view of actual shearer position

2.2 *Horizon Control*

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

- The base input uses the vertical shearer position information available from the SMPDS. The current floor horizon is derived by extrapolating the floor profiles of a number of previous shears. This information can also be added as extra inputs to the existing OEM memory cut horizon control systems.
- Outputs from real-time coal interface detection (CID) systems can be used to provide inputs to the cut model either in real-time to the current shear or to enhance the predicted floor profile for subsequent shears. Particular CID sensor developments will be discussed later.
- According to the principle of on-face observation, the cut model can also accept on-line inputs from operators to modify the horizon parameters.

The Landmark automation system builds up a data-base of the extracted seam profile by adding actual floor and roof measurements at each shear. Figure 1 also shows the as-mined seam floor profile extracted from actual shearer position information.

As well as the cut model, a seam model has also been developed. This model is based on historical information such as borehole and seismic exploration. Although these data give valuable information on seam geometry and geotechnical properties, in general the resolution is too coarse for them to be used for real-time equipment control. So that the information can be utilized effectively, the seam model is used to place bounds on the horizons predicted by the cut model. When such predicted horizons intersect the seam boundaries predicted by the seam model, warnings are generated to check the information being generated by the cut model for validity, usually by on-face observation.

A method called the ‘controlled traversing cut’ has been generated to enable effective horizon control through fault conditions. A prerequisite to the application of this technique is that high-resolution 3D modeling data for the area in question at the minesite is available to input to the controlled traversing cut process.

Work is in progress on investigation and development of automated CID systems to provide inputs to the cut model. This is an area of research and development that has attracted significant research effort since the 1970’s (Hainsworth 1997) but with few operational outcomes. Sensor development has concentrated on two areas:

- Heating of roof and picks. When hard roof strata is encountered, picks and the roof itself are heated. Thermal infrared sensing can detect subtle temperature differences caused by cutting non-coal material. A small thermal camera is being mounted on the shearer to identify when the drum has contacted the hard roof of the test mine.
- Optical detection of marker bands. Initial industry surveys showed that one of the most common horizon control techniques used by shearer drivers is based on the use of visual markers in the seam profile. Preliminary experiments have shown that marker bands can be automatically detected and work is currently concentration on implementation across the face.

2.3 *Communications and Operator Interface*

An early project requirement was the development of a reliable shearer maingate communications method for the transfer of 3D shearer position data. Currently, other broadband shearer-based services such as video and intelligent sensor data are being introduced. In addition a redundant shearer maingate communications system based on broadband power line carrier technology is under development. As the level of automation of face systems increases during the project, the number of operators in the immediate face area will reduce. Sensor systems will be developed to replace the observation functions of on-face personnel. Some of the observation functions will be carried out remotely at the monitoring station using video cameras placed on face equipment.

A wireless Ethernet (IEEE Standard 803.11b) link was established to the shearer used as the test platform. The system is based on commercial products which have been appropriately packaged for the mine environment. This ensures that technology developments which occur at a fast pace in communications and networking can be easily implemented in the system. Similar technology is currently being used to transport the wideband communications necessary for observation and monitoring functions required in later project stages.

One of the issues facing this aspect of the project is the development of a commonly accepted, industry-wide data communications protocol to permit information flow between longwall equipment from various vendors. Data transfer between Landmark hardware and shearer and powered support systems is of critical importance. Establishment of an appropriate protocol was also an initial goal of the project. EtherNet/IP, a recently developed industrial automation communications protocol, has been agreed by at least three major equipment manufacturers as the data interchange standard to be used for the Landmark project. Using an open system such as this is beneficial during the Landmark project equipment development stage where negligible access to OEM intellectual property is required by researchers during product development.

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.

Work is also progressing on the definition of higher-level communications requirements for transfer of shearer and support motion control.

2.4 *OEM Involvement*

This is a key outcome for the success of the project. Manufacturers of longwall equipment need to be committed to the Landmark project process to enable technical outcomes to be incorporated into future machine specifications. In addition, their direct involvement in the project assists transfer of project results to the mining industry at best practice. 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 in place.

A complex issue confronted by the project and by OEMs in general is that of safety, where suppliers of equipment have legal obligations regarding the safe operation of their products. When products from several vendors are interconnected in an operation that may be required to operate in an automatic, semiautomatic or manual fashion, depending on the level of automation at a particular installed site, predictable performance is necessary in all cases.

Problems can arise if a control system from another vendor directly commands motion of a particular system. In the Landmark project, all motion commands, whether from an automation controller or operator are filtered by the internal safety mechanisms. Such commands are referred to as motion recommendations rather than commands. 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.

2.5 *Information Systems*

The following work areas address the requirements of the information system development outcome.

- Monitoring Station. This is required close to the face to facilitate both on-face observation and the development, testing and commissioning of automation systems. As the automation process matures, the monitoring station can be further withdrawn outbye.
- Visualisation Systems. Operator confidence in an automation system is enhanced through accurate visualisation of current equipment operation and face conditions. Visualisation software to produce high quality representations of the state of the longwall system on the underground monitoring station user interface is currently under development. Visualisation models, an example of which is depicted in Figure 2, have been created.

Figure 2 Longwall visualisation

- Exception reporting systems to utilise existing OEM-derived condition monitoring and operational data as well as extra information from Landmark sensors are under development. These will form an integral part of the automation system user interface.
- Automatic process design. The face alignment and horizon control automation systems described above act in general as closed loops. They require only periodic adjustment of operating parameters and do not require constant control by face operators. On the other hand, for full automation and removal of operators from the immediate shearer vicinity it is necessary to supply equivalent real-time inputs to the shearer to those now produced by an operator using a radio remote control.

As well as responding to observations of face conditions, an operator produces inputs to the shearer based on his understanding of the required higher level extraction process. An automation system must generate an equivalent sequence of inputs to the shearer to accomplish the physical operations necessary to implement a particular extraction scheme. As a first step, process maps to characterise current longwall mining extraction methods were established. Based on this framework, scripts and sequences to transfer current best practice to the automated system have been developed. The next stage is to trial these at the test site.

2.6 *Production Consistency*

Many of the functions carried out by on-face personnel are not concerned with actual on-line control of mining equipment operation. These functions 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 current project. In this mode of operation, video systems are used to relay face and gate road geotechnical conditions to the monitoring station. However a number of project activities are concerned with development of automation systems to carry out key monitoring functions.

- Collision avoidance: Work has commenced on development of a system to measure the separation distance between the shearer and roof support components.
- Coal flow optimisation: A visual monitoring system to detect face and production anomalies such as oversize coal lumps, conveying blockages, and development of face and roof voids will be implemented in the third year of the project. This will be achieved through video monitoring systems displayed in the monitoring station, where changes to the operation can be made.
- Convergence monitoring: The latest developments in support leg convergence monitoring

methods will be analysed, and software will be developed to monitor and analyse leg pressures on-line to assist in predicting chock weightings along with the fusion of other geophysical data.
- Void monitoring and response: As well as the use of visual monitoring methods, a survey will be conducted of other sensing methods that are applicable to detection of voids.
- Gateroad monitoring: In the third year a monitoring system for gateroad deformation will be built and field trialled. This will use laser and extensometer-based measurement systems.

2.7 *Condition Monitoring and Reliability*

The production delay records for the past three years were analysed in detail for one of the project sponsors. Mining delays as well as interruptions to the production due to equipment failures (recorded as planned and unplanned maintenance) were included in this analysis.

On average, about 50% of all downtime was found to have been attributed to planned and unplanned maintenance. This is a substantial number. A Pareto analysis showed that 30% of failure categories account for over 90% of total equipment-related downtime and the top ten failure categories account for well over 50%.

While Pareto analysis is useful in identifying the top failure categories, a more discriminating analysis is offered by using scatter-plot representation.

A scatter plot is basically a logarithmic plot of mean time to repair against the number of failures. Since the total downtime associated with each equipment failure is the product of the two, constant downtime curves appear as lines on logarithmic axes. The scatter plot for the period under consideration is presented in Figure 3.

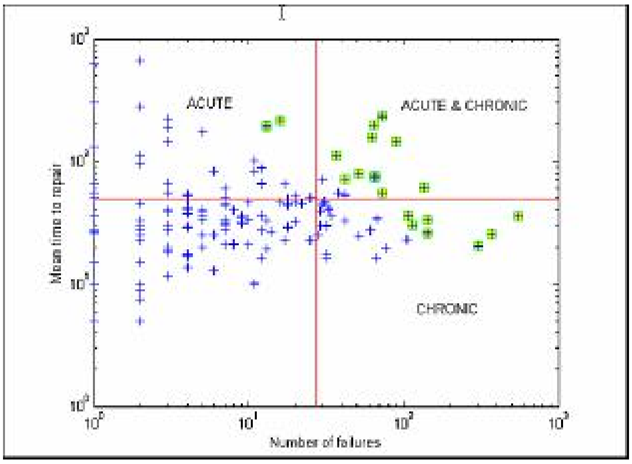

Figure 3. Scatter plot representation of failure histories

Each point on this plot refers to an individual failure category. The identities of these failures are currently under review by the project sponsors and would be released in the final report for the project. In the context of the present paper, it is sufficient to note that the plot area is separated into four quadrants as shown. The lower left quadrant includes those failures that do not appear too often and when they do are easily fixed. The attention should be focused on the other three quadrants: Acute; Chronic; and Acute & Chronic.

Chronic failures are relatively easy to fix when they occur but they still cause significant amounts of downtime. Acute failures are rare, but they have a long repair time. A substantial number of acute failures may be indicative of the need for further product development.

The most striking result is the number of failure categories that are both acute and chronic. Some failures of this nature may be unavoidable during commissioning stages of new equipment. Persistence of such problems may be an indication of problems in the original design and/or selection of the equipment.

Our current research area is progressing along two fronts: improved tools for design for reliability; and improved tools for condition monitoring.

Under the heading of computer-aided tools for design and/or selection of longwall equipment, the following suite of software tools is at an advanced stage of preparation:
- Prediction of chain speed, dynamic chain tensions, and sprocket tooth loading in armoured-face conveyor chains — with capability to simulate systems with different configurations including CST or fluid coupling power transmission.
- Prediction of dynamic forces and vibrations during shearer operation — with capability to simulate systems with lacing patterns under different cutting modes.

In the area of condition monitoring, the following products are being targeted:
- Fault detection and isolation software based on a bank of parallel classifiers including neural networks and model-based detectors.
- An on-line estimator that will estimate individual pick forces from measured vibrations and motor currents. Such an estimator will have several uses:
  - Health monitoring of the shearer power transmission.
  - Monitoring the condition of the individual cutting picks.
  - Mapping the cutting effort against the face geometry and use such mapping to identify the locations of discontinuities or hard bands to help with the horizon control of the shearer.

2.8 *Training: Redefined Functions of Face Operators*

One of the keys to the successful implementation of longwall automation systems is recognition that the skills required in an operator of an automated system are different to those presently required on the face. Attention must be paid to staff selection and training.

An on-line training system is being set up utilising the monitoring station. 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. The training process will be refined as mine operational personnel gain more experience with the automation system.

2.9 *Minesite Trials and Demonstrations*

The project budget provides for field trials and demonstrations of all the developed technologies at one location. The possibility of incorporating subsequent sites to trial different OEM equipment combinations is currently under investigation.

2.10 *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 2004.

2.11 *Implementation Plan for Progressive Automation*

This activity will benchmark all longwall mines in Australia and will 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.

3 CONCLUSIONS

The ACARP landmark process has afforded the underground coal industry with a tremendous opportunity to develop and implement cutting edge technologies into a package that will provide an automation capability for longwall operations. Key new developments in inertial navigation and information technology from other industries will assist this process. The benefit for the industry will be a potentially higher, more consistent production rate and the removal of face workers from more hazardous areas.

The project has been running for two years and several important milestones have been achieved:

- On-line 3D shearer position information is now routinely available.
- Wireless Ethernet has been shown to be a viable, robust face communications system
- EtherNet/IP has been adopted as the standard for communications between OEM and Landmark control systems.
- 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 benefits of other-industry technology development (INS, thermal imaging, processor control, data communications) are being transferred successfully to longwall automation.

Although the task remains complex, the risks are relatively low as most of the technologies have been proven in other areas. The focus on productivity and designing the system for exception issues will also ensure a lower risk and provide an incentive for progressive operations to uptake the automation technology. The onus will be on the project team to communicate these outcomes progressively so that companies may include “Landmark Compliant” longwall specifications into future orders and upgrades.

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