The Landmark Longwall Automation Project

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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 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 paper discusses project outcomes which have been divided into a number of areas, each addressing a specific requirement of a successful longwall automation process. The cornerstone of these, automatic face alignment, has been successfully demonstrated underground. The project has the support of major longwall equipment manufacturers including Eickhoff, DBT and Joy Mining Machinery.

1 INTRODUCTION

Longwall automation can deliver benefits to the industry in terms of increased productivity and improvement in conditions for current on-face workers, particularly by removing them from hazards. Automation work has been proceeding steadily for many years but with less than expected delivery of benefits to the industry. 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 on operators actually 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.

With this background CSIRO and CRC Mining commenced the ACARP Landmark Longwall Automation Project in August 2001. This paper presents the status of the project near the end of its 3-year duration.

2 LONGWALL AUTOMATION – TECHNICAL ISSUES

The technical requirements to automate a longwall face can be summarized as follows:

Keep the face straight and on track.

This requires the development of equipment that measures the face profile and feeds this information back to existing OEM roof support control systems to achieve a desired face alignment. Sensors are also required to measure the misalignment of the face with respect to the gate roads due to creep and to use this knowledge to steer the face in order to minimize creep. OEM face alignment automation systems currently lack a robust method of measuring face profile consistently during production.

Keep the face in the seam

Horizon control is a vital part of the mining process. Currently shearer drivers use their senses to extract a wide range of cues to determine mining horizons. Existing horizon control automation systems lack robust sensing of both the exact vertical profile of the seam and the extracted section.

Integrate the operation of all components

The longwall face may comprise equipment from a number of vendors. Automation requires the wide band communication of information between system components. Currently the use of proprietary communications systems limits the effectiveness of integration of system components.

Have effective geotechnical monitoring

Face operators continually monitor the geotechnical environment in order to anticipate problems that might interfere with production. Automation system developers must also address this issue.

Achieve necessary system reliability

The technology in automation systems makes the entire production equipment chain more complex. Appropriate robust equipment is necessary to achieve industry-standard availability.

Manage the exceptions

This is perhaps the most important problem facing the longwall automation process. Enormous progress has been made in factory automation over the past few decades. While the ultimate goal is to make a mine a coal factory, the reality is that a longwall face is not a factory floor. Identification and management of all the exceptions that are possible in an automated environment requires 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.

Consequently, ‘on-face observation’ was adopted as 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.

3 PROJECT AIMS AND OUTCOMES

Based on the principle of automation with on-face observation, a number of separate but related research areas were identified 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:

- 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
- Mine site trials and demonstrations
- Acceptable commercialisation plan
- Implementation plan for progressive automation

The paper will discuss results obtained in key outcome areas. Work has concentrated on the outcomes leading directly to automation of basic equipment functions including face alignment, horizon control, open communications, and information system.

Face Alignment

The goals are to automatically maintain face geometry by measuring the actual 3D position of the shearer in space using an inertial navigation system (INS) and to use that information to control the movement of the powered supports.

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 supplied the first deliverables of the project. The various technology components, particularly those already present on OEM equipment, are in advanced stages of development.

A real-time shearer position measurement system (SPMS) to provide accurate measurement of actual shearer position in space in real time has been developed. This system also provides for logging of shearer position for later analysis. An INS has now been operating on a shearer in five consecutive extraction panels.
This is a stand-alone outcome on which the remainder of the automation system has been built.

The roof support OEM at the test mine has developed software to accept the SPMS face profile information over a standard communications interface, and to utilize it to provide closed loop control of support motion. . Successful tests have been carried out at the test mine showing automatic face alignment producing a desired face geometry can be achieved.

A sensor based on scanning laser rangefinder technology has been developed to measure the position of the main gate infrastructure in the gate road cross section. This enables the creep motion of the longwall to be measured. Creep distance is then used to adjust the tailgate offset (lead or lag) so that the longwall can be steered to reduce the creep distance automatically.

Horizon Control

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 information is passed to the shearer control system over a standard communications interface. The cut model is able to accept inputs from various sources.

The basic input uses the vertical shearer position information available from the SMPS. The Landmark automation system builds up a data-base of the extracted seam profile by adding actual floor and roof measurements at each shear. The current floor horizon to be followed is derived by extrapolating the floor profiles of a number of previous shears. This information is then added as extra, accurate inputs to the existing OEM 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.

According to the principle of on-face observation, the cut model can also accept on-line inputs from operators to modify the horizon parameters.

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 introduced to enable effective horizon control through fault conditions. Use of the controlled traversing cut concept requires two prerequisites. High resolution 3D modeling data for the area in question at the mine site must be available to input to the controlled traversing cut process, and the current vertical shape of the face must be measured accurately by the Landmark system.

Work is in progress on investigation and development of automated CID systems to provide inputs to the cut model. This is an area of R&D 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 has been 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 concentrated on implementation across the face.

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. Subsequently other broadband shearer-based services such as video and intelligent sensor data have been introduced. In addition a redundant shearer maingate communications system based on broadband power line carrier technology has been lab tested and is being installed underground. 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 by minimising researcher access to OEM intellectual property 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.

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.

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.
– *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.

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*: Scoping work has been completed 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 is currently being implemented underground. Video monitoring systems displayed in the monitoring station will enable changes to the operation to be made.
- *Convergence monitoring*: The latest developments in support leg convergence monitoring methods have been analysed, and software has been 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 of other sensing methods that are applicable to detection of voids is under way.
- *Gateroad monitoring*: A monitoring system for gateroad deformation has been built and is currently being field trialled. This uses laser-based measurement systems.

Condition Monitoring and Reliability

This section of work is being conducted by CRC Mining. This work is reported elsewhere in the conference.

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 mine site 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.

Implementation Plan for Progressive Automation

This activity benchmarks 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.

4 CONCLUSIONS

The ACARP landmark process has afforded the underground coal industry 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 three 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 up-grades.

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