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Sensing for advancing mining automation capability: A review of underground automation technology development

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ABSTRACT

This paper highlights the role of automation technologies for improving the safety, productivity, and environmental sustainability of underground coal mining processes. This is accomplished by reviewing the impact that the introduction of automation technology has made through the longwall shearer automation research program of Longwall Automation Steering Committee (LASC). This result has been achieved through close integration of sensing, processing, and control technologies into the longwall mining process. Key to the success of the automation solution has been the development of new sensing methods to accurately measure the location of longwall equipment and the spatial configuration of coal seam geology. The relevance of system interoperability and open communications standards for facilitating effective automation is also discussed. Importantly, the insights gained through the longwall automation development process are now leading to new technology transfer activity to benefit other underground mining processes.

1. Introduction

1.1. Motivation and purpose

The Commonwealth Scientific and Industrial Research Organisation, CSIRO, is Australia's national science organization which delivers innovative solutions into industry domains around the world. CSIRO also focuses mission-directed mining research to promote transformational change in the mining and resource ecosystems. A major emphasis of the research activity is in the development of remote and automated mining technologies to support safer, cleaner, more productive and sustainable mining. Critical to delivering on this mission is continual development of new sensing system technologies.

1.2. Industry needs

The Australian coal mining industry is constantly driven by the need to improve mining productivity, increase personnel safety, and achieve environmental sustainability [1,2]. Underground coal mining presents many hazards including personnel proximity to machinery, high energy hydraulic and electrical power systems, roof falls and exposure to explosive mine gases and dust. Historically personnel have been required to work in this hazardous environment and manually control the equipment at close range to ensure the efficient operation of the mining process. The complexity of manually operating equipment of this scale has led to the full productivity of longwall systems not being achieved, and the harsh and hazardous working environment has potential health and safety concerns for personnel [3,4].

Mining automation system technology demonstrates significant potential to meet these needs by facilitating more accurate mining methods, incorporating sensing to optimally control equipment, and increasing personnel safety through remote process operation. To this end, this paper explores the impact of automation technology innovations for the automation of underground longwall shearer mining equipment.

1.3. Architecture for mining automation

From a system architecture perspective, effective mining automation requires the integration of three key components: sensing, processing, and control. These fundamental components must interact in a continuous cycle as the underlying resource is dynamically sensed, modified and transported through the process of mining. This mining automation cycle in Fig. 1 shows the three "sense, decide, and act" components dynamically operating in concert with the mining process. These three elements respectively represent the underlying mechanisms that provide situational

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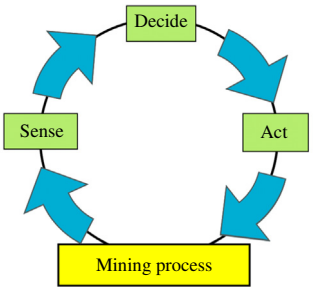

Fig. 1. Mining automation cycle showing three key technology elements necessary to achieve remote situational awareness (sense), perception and decision support (Decide), and mining execution and control (act).

awareness, decision support, and process management functions necessary to achieve a closed-loop mining automation cycle.

The rationale underpinning development of mining automation system technology is the drive to improve personnel safety and enhance operational efficiency. This is primarily achieved through the integration of new sensing, processing, and assistive control technologies into the longwall mining process. The introduction of new capabilities often also provides new options for cleaner coal recovery through coal seam sensing capabilities and improved mine process awareness.

1.4. Level of mining automation capability

A continuum of automation capability exists from local manual control through to full automation. The following discrete levels have been identified to provide context for identifying the desired automation level:

(1) *Local manual control:* where the operator has immediate line-of-sight of the mining process through a hard-wired, direct-connect machine control interface.
(2) *Remote manual control:* where the operator has immediate line-of-sight of the mining process but achieves direct drive control via a portable console interface.
(3) *Tele-operation:* where the operator does have a line-of-sight but directly controls the mining process through sensors that provide mining situational awareness.
(4) *Tele-supervision:* where the operator does not have line-of-sight but initiates and monitors the mining process at a high level, facilitated by assistive automation technologies.
(5) *Full automation:* where the operator has no line-of-sight or immediate direct machine control, and most or all components of the mining process are functioning autonomously.

The specific level of automation achieved is governed by the minimal automation level of any given component in the overall automation cycle. There are a wide variety of mining scenarios which still require mining personnel to manually undertake the sensing, processing and execution functions. This has important safety and efficiency implications, with corresponding productivity and sustainability impacts to the overall mining process.

1.5. Longwall mining background

Longwall coal mining is a highly productive underground mining method that involves the removal of coal in large blocks or panels using a mechanized shearer. The coal panel is typically 200–350 m wide and can be up to five km in length. The shearer is mounted on a shearer pan and rails which guide the shearer as it moves back and forth across the coal face [1,5]. Coal cut from the face of the longwall by the shearer is removed by an armoured face conveyor (AFC) that transports coal to the adjoining gateroad tunnels for conveyance to the surface.

With this method of mining, the roof is supported by hydraulic shields that are individually advanced as mining progresses. As the roof support system advances into the coal panel, the mine roof is allowed to collapse into the void behind the shields. A small portion of a longwall operation and shearer is shown in Fig. 2.

As noted in Fig. 2, the direction of mining is into the coal seam on the left hand side of the image, and the coal seam is indicated by the hatched layer between the underlying and overlying strata. Singh further detailed technical reviews of the longwall mining process [1].

1.6. Need for operational improvements

The underground mining environment can present many operational hazards to personnel. These include proximity to powerful machinery, hydraulic and electrical power, roof falls and exposure to dust and potentially explosive mine gases. In the absence of advanced automation, miners have for decades been required to work in this hazardous environment to manually control the equipment at close range to ensure the efficient operation of the mining process. The industry recognized that this was increasingly unacceptable and unsustainable in the long term and sought answers to these problems.

Since 1970s, there have been a number of attempts world-wide to develop longwall automation systems [4,5]. These had been largely unsuccessful because it had not been possible to accurately and reliably measure the positions in space of the principal elements of the longwall due to a lack of proven sensing capabilities.

1.7. Longwall automation program of Longwall Automation Steering Committee (LASC)

In response to these issues, the Australian Coal Association Research Program (ACARP) provided "landmark" funding for CSIRO to undertake an ambitious research and development program to develop an advanced longwall automation system. The research project commenced in 2001 and was overseen by a Longwall Automation Steering Committee (LASC), the name now given to the resultant technology solutions [5,6]. Through this research, enabling technology was developed that was designed to not only remove personnel from hazardous environments and improve productivity but also to provide open standards for future equipment interoperability.

The research project commenced by conducting a detailed analysis of what aspects of the longwall mining process could be realistically automated, as well as investigating what could be learned from previous attempts at technology development and deployment in this application. From this analysis, three priority automation tasks were identified:

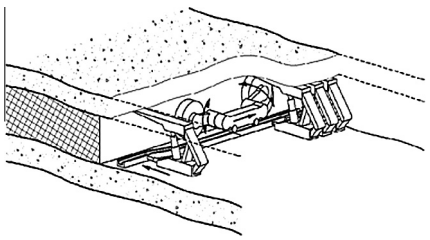

Fig. 2. Cut-away view of the underground longwall mining process (the shearer is in centre view, mechanised roof supports to the left and right, and embedded in coal (hatched) and host strata (dots)).