APPLICATION OF SIGNAL PROCESSING TECHNOLOGY FOR AUTOMATIC UNDERGROUND COAL MINING MACHINERY

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ABSTRACT

This paper reports on an industrial application of modern signal processing technology in the development of a new automatic conveyor and bolting machine for underground coal mining. The machine is of special interest to the mining industry as it improves mine personnel safety as well as increasing the efficiency of roadway construction. We show how real-time signal processing component technologies are needed to overcome a range of sensing, monitoring, control, and navigational challenges. We also highlight some of the important practical issues associated with the deployment of intelligent processing systems in coal mining contexts.

1. INTRODUCTION

There is a constant need in the underground coal mining industry to improve productivity and personnel safety. One of the key areas for automation is the development of the core roadway infrastructure in underground coal mines. Roadway development is a complex, expensive and time-consuming process involving a combination of different mining machinery to cut a lattice network. The main performance bottleneck in roadway development is the need to constantly halt mining to allow the installation of supporting bolts to prevent the roadway from collapsing. Moreover, the current practice of manually drilling and bolting is one of the most dangerous tasks in underground coal mining, involving significant safety concerns for mine personnel. A real need therefore exists for a rapid roadway development system to minimize personnel exposure to hazardous areas of unsupported roof, as well to improve the overall production rate of this vital mining activity.

In an effort aimed at addressing these key safety and productivity issues an innovative new machine, known as the Automatic Conveyor-Bolting Module (ACBM), has been designed [1,2]. This paper overviews the main signal processing technologies involved in realizing the level of automation required by the ACBM. The ACBM involves a combination of processing systems in order to provide online roof monitoring, roadway profiling, navigation, and automatic control of drilling and bolting processes. The block diagram in Figure 1 shows the control hierarchy between the central control unit and associated signal processing components to achieve this goal.

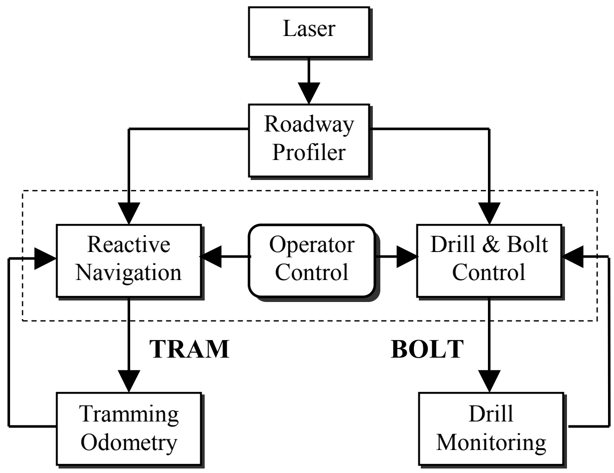

Figure 1: Block diagram of the main signal processing component technologies associated with the ACBM.

Section 2 introduces the functionality of the ACBM and describes internal processing and control architecture. Section 3 presents a laser-based profiling system used for roadway characterization and ACBM navigation. Section 4 overviews the drill monitoring system used for online seam characterization. Section 5 presents salient practical details on the implementation of the system in a harsh underground environment.

2. ACBM FUNCTIONAL OVERVIEW

The ACBM is a mobile platform fitted with independent bolting rigs, coal receiving hopper, bolt storage and delivery system, and a through-conveyor for coal transport. It is designed to follow the path of a continuous miner as it drives a new roadway, automatically inserting roof and wall bolts. While creating the roadway, coal cut from the tunnel is also transferred via a through conveyor to a belt leading from the mine as shown in Figure 2.

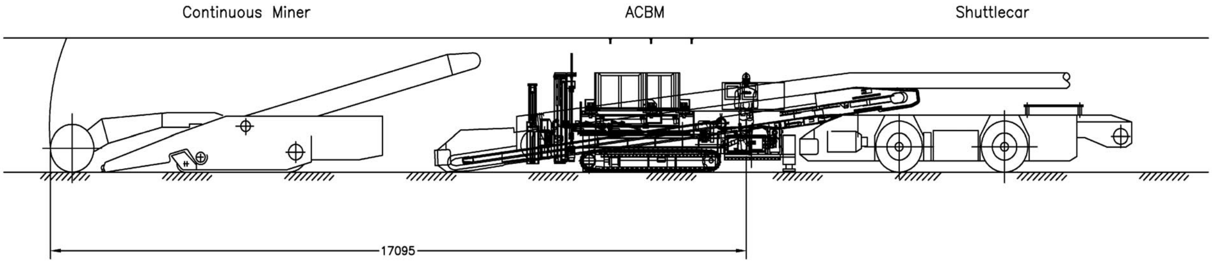

Figure 2. Diagram showing the arrangement of the ACBM platform with respect to the miner and shuttle car. The ACBM's dimensions are 12 m x 3 m x 2 m and weighs 50t.

The ACBM control system has two fundamental operating modes, namely tramming and bolting. The cycle time for placement of a row of four bolts is 4.8 minutes, allowing a machine advancement rate of 15 m/hour with a 1.2-meter row spacing. The ACBM is a mobile platform with an average tram rate of 15 meters per hour. The system draws together international expertise in manufacturing, geophysics, modeling, ventilation, visualization, and engineering [1].

2.1. ACBM Processing and Control

As the ACBM may be interposed between various production and coal haulage machines, the system has been designed to work either independently or in concert with a modified remote controlled miner with remote controlled bolting capabilities.

The ACBM uses a centralized unit for the intelligent control and coordination of a set of distributed computing and sensing modules. The central unit is responsible for ACBM tramming, bolting, and conveyor tasks, as well as generic supervisory tasks such as link/device integrity monitoring and system-wide safety. The aim of the control system is to execute the necessary control over the robotic bolting and motion systems in order to implement the required bolting pattern. The bolting control system is designed to place up to six bolts in a row, oriented from a vertical placement to an outward angle of 15 degrees with a maximum vertical reach of 3.7m from the floor.

Although the ACBM is designed with fully automatic drilling and bolting capabilities, the system can be set into semi-automatic or manual modes. This permits the operator to elect the operational mode. A graphic user interface allows operators to interact with the system.

2.2. Software Architecture

The integrated signal processing component technologies are implemented at three orthogonal layers: Validation, execution, and functional layers. The validation layer has the highest priority and is responsible for top-level intersystem and intermachine coordination, system mode resolution, integrity monitoring and other safety related logic decisions. The execution layer controls and coordinates the dynamic execution of main functions such as drilling and bolting sequencing, profiling and drill monitoring. The functional layer contains modules that encapsulate all device specific interface and control details (such as drivers and communication protocols) for the sensors and actuators of the machine. The software design serves to effectively decouple the low-level safety functions from the real-time signal processing activities. The architecture also greatly facilitates the incorporation of new devices or new machine behavior.

2.3. Rapid Prototyping: The EVPLC Framework

The complex algorithms needed for the real-time process and control of the four asynchronous drilling and bolting rig sequences present a clear implementation challenge. This led to the construction of a novel rapid development environment specifically intended for prototyping and deploying the ACBM processing and control algorithms.

The development framework is based on the concept of an enhanced and virtualized programmable logic controller and is known as the EVPLC rapid prototyping system. It is realized through an object-oriented parallel finite state machine. As the underlying implementation is based entirely on the C++ standard template library, the implementation is clean, efficient, and readily scalable.

Using this framework, control and processing behavior is created entirely through run-time configuration data, rather than through the code. This has significant benefits in terms of the speed at which system modifications and enhancements can be implemented. The system thus provides a rapid prototyping environment for DSP and control processes, and enables dynamic reconfiguration of system behavior: a key feature in industrial scenarios where system specifications are frequently modified.

3. LASER PROFILING AND NAVIGATION

Four independent laser measurement sensors are used to provide cross sectional roadway profiling and navigational information [3]. A fifth sensor is reserved for analysis of coal-flow on the through-conveyor and is discussed elsewhere. The laser sensor data is augmented with independent tramming (odometer) inputs for secondary platform motion validation. The machine does not rely on additional infrastructure such as waypoints or reflective tape for the profiling and navigation tasks.

3.1. Roadway Profiling

Cross sectional profiles of the roadway are required at prospective locations to ensure that the drilling rigs are optimally orientated for bolt placement. Ideally, the roof and rib (side wall) surfaces should be perpendicular to the respective bolting rigs and the distance to the surface must be within the limits of the rig stroke. If these conditions are out of tolerance the bolting process may fail.

The profiling process can thus warn the operator and also search for a better location for bolt placement. Figure 3 shows a series of typical tunnel cross-sectional profiles acquired as the ACBM progresses through the roadway.

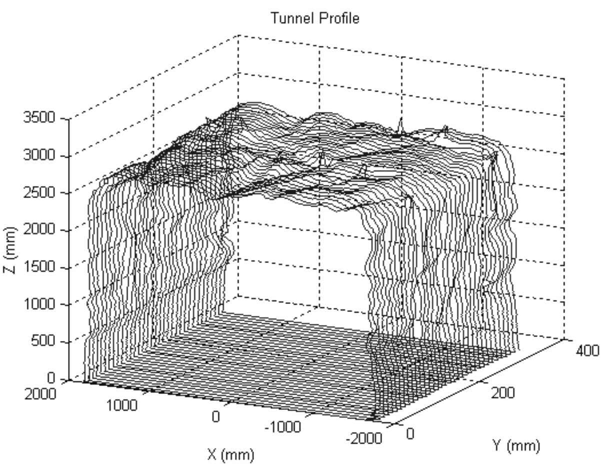

Figure 3: A typical laser scanned profile generated as the ACBM trams along the roadway.

3.2 Navigation

The laser sensors also provide important information for navigational purposes. It is necessary to maintain a suitable separation between the ACBM and the miner for coal flow management, and to provide a collision avoidance mechanism when the ACBM-miner separation is too small. Optimal bolt placement also requires that the orientation of the ACBM be positioned along the centerline of the roadway, i.e., equally displaced from the ribs. Given the relatively slow velocity of the platform and the constrained tunnel environment, a conventional reactive navigation algorithm provides a simple and robust method for both collision avoidance and ACBM orientation. Figure 3 shows the physical arrangement of the ACBM in the roadway.

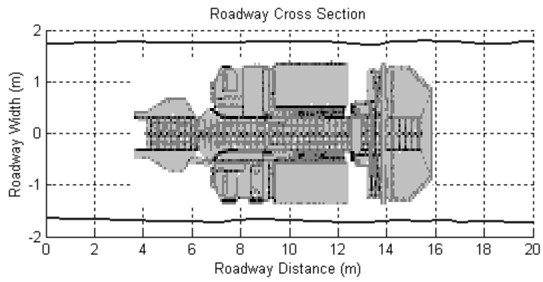

Figure 4: Roadway data derived from the laser profile for ACBM navigation.

4. DRILL MONITORING SYSTEM

4.1 The Need for Drill Monitoring

It is critical for safety that the supporting bolts are securely anchored in strong, solid rock. This means that not only must the bolt be appropriately torqued when fastened, but also that the basic composition of the strata be known. Although predictive coal interface detectors have been considered for this class of problem [4], the need to drill and bolt for roadway integrity supports a more direct approach.

The need for drill monitoring is particularly important as a machine is replicating a function normally fulfilled by an experienced underground operator. To this end, an online in-situ drill monitoring system is needed in order to assess the quality of the bolting process and provide information on rib and roof integrity.

4.2 Neural Network Classifier

The drill monitoring system is designed to detect layers, cracks and discontinuities in the drilled strata. The roof drilling rigs on the ACBM are instrumented to provide sensor feedback during each drilling and bolting phase. The key physical parameters measured for drill monitoring purposes are torque, rotational rate, thrust, and penetration rate. These signals are shown in Figure 5.

An important parameter used in drill monitoring is the specific energy of drilling (SED), which expresses the linear and rotational energy needed to drill a given volume of material, i.e.,

$$SED = F/A + W\tau / Ad$$

where F is the thrust force, A is the area of the drill hole, W is the drill rotary speed, τ is the drill torque, and d is the drill displacement [6]. SED is of special interest for strata characterization problems as it can be used to determine the relative strengths of strata and geological features.

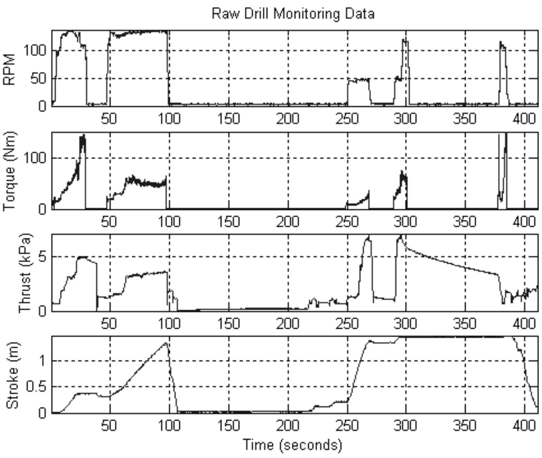

Figure 5. The drilling parameters measured for drill monitoring: RPM, torque, thrust, and stroke.

Other metrics such as torque over thrust can also be used as feature inputs [5]. The drill monitoring process consists of three major components: Data acquisition, feature conversion, and strata classification. A neural network based classifier is used to estimate the characteristics of rock strata, where the SED derived from the drill monitoring data provides an additional feature for the classifier. The neural network architecture is particularly well suited to this classification problem due to the highly nonlinear and time-varying characteristics of the drilling process. A detailed survey of the ACBM neural network classifier implementation can be found in [5].

5. PRACTICAL IMPLEMENTATION ISSUES

Special design and construction considerations are necessary in order to make the processing equipment suitable for use in an underground coal mining environment.

There are many challenges developing electronic hardware that can withstand the hostile conditions of the underground coal mining environment: Water, vibration, dust intrusion, shock, and heat all impact on system reliability issues. As a result, the ACBM uses ruggedised PC104-based industrial modules for all signal and control tasks. The modules have proven to be an effective platform for delivering the required processing power under adverse conditions.

In addition, the computing systems need to operate in presence of potentially explosive gases and thus need to be intrinsically safe. This requires that the ruggedised processing modules be placed into flameproof enclosures in order to ensure that they present no explosion risk.

6. SUMMARY

This paper presented the novel application of integrated signal and control processing to address an important automation problem in underground coal mining. The immediate implications of the ACBM include the removal of personnel from hazardous areas of unsupported roof, as well as the potential to significantly improve the rate of roadway development. A key to the success of the system is its combination of modern signal and sensor processing technology. Future machine enhancements are likely to include the addition of an inertial navigation system in order to provide a more complete mine-wide automation system.

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