CONTROLLING A THIN-SEAM MINER 500 FEET FROM THE FACE

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ABSTRACT

This report summarizes work sponsored by the Bureau of Mines in the development of a remote operating system (ROS) for controlling a thin-seam continuous miner (TSCM) 500 feet or more distant from the extraction face. Details are provided on ROS subsystems including the continuous miner, video equipment, controls and displays, the electronic control system, and the operator station.

INTRODUCTION

This project was undertaken to determine the feasibility of remote, out-of-sight operation of a TSCM using off-the-shelf equipment. If remote operation becomes a common, practical alternative to present mining methods, the industry should profit from significant safety gains, increased flexibility in selecting mining strategies and expanded recovery of coal reserves.

Without question, the safety of workers can be increased by removing them from the vicinity of hazards. Thus, controlling a TSCM from a remote, protected station appears an attractive method to dramatically increase deep mine operator safety because the operator is removed from the 25-ft zone adjoining the working face, widely documented as the most hazardous area in all mining. A stationary control station does not have to share the extraction area with mobile machinery and clearances necessary for tramming; it can fully utilize the available space for the operator envelope and a surrounding protective structure. Remote operation also removes operators from face area, health and congestion problems and increases their comfort.

ROS methods are not limited to current mining systems or extraction locations; they may allow the deployment of modified, current-generation equipment in new applications and make feasible the mining of reserves presently considered "unminable."

In 1979, the Bureau issued the Bendix Corporation Contract No. H0308038 to study the feasibility of a ROS for a deep mining TSCM. The study showed the concept was attractive in both safety and economic terms and an initial design was developed [1,2]. In 1983, the Bureau assumed the project completely in-house and fabrication of an up-dated system commenced.

DESIGN OF THE ROS

To reduce system complexity and cost, remote operation was considered only during cutting and loading processes; movement of the continuous miner from face-to-face was to be conducted by standard methods. A comprehensive activity analysis was performed for remote, within-sight continuous miner operation at 2 southwestern Virginia mines. This was done to insure the ROS design would account for the full inclusion of tasks and individual variations in task performance for operators and their helpers, the two job classifications most affected by the planned remote operation. Conclusions from the study indicated that: 1) the concept was feasible from safety, technological and economic viewpoints; 2) an operator's primary means of obtaining equipment control information is through vision; and 3) significant safety gains could be achieved by minimizing the presence of miner helpers at the face area.

Based on the conclusions and project goals, the following list of preliminary specifications was derived for the ROS: 1) the operator be placed in a ground-fall-protected station near the section's electrical load center, a location relatively safe, not heavily traveled, and comparatively close to other activities and workers; 2) the ROS sensory, display and control subsystems include computer support and allow efficient miner operation; and 3) an automatic subsystem for handling the water, power and signal lines be designed for the TSCM to minimize the need for a miner's helper being at the face during mining.

Continuous Miner

Investigation of the available TSCMs resulted in selecting the Jeffrey model 101/102 for use in the project. This selection was based on a comparison of the design and specifications of each TSCM and included the preparation of drawing board layouts of the machines with the addition of several configurations of anticipated ancillary equipment. The advantages of the model 101/102 machines over others include that: 1) the flat upper surface allows television cameras to be placed in a variety of positions with relatively unobstructed fields of view; 2) more space is available for add-on equipment; and 3) more precise control of the extraction process is feasible because the cutting auger is sumped into the face by hydraulic rams while the main body of the miner remains stationary.

Cameras

Using layout drawings of viewing areas, it was determined that 2 cameras could provide the necessary visual information if they were properly located on the miner and equipped to allow individual control of viewed scenes. Two high sensitivity, solid-state color cameras (Sony model DXC-102) mounted in custom-made explosion-proof housings were selected. The cameras are equipped with 11 to 110 mm zoom-type lenses. Camera placement on the miner was designed to enable one camera to look toward the extraction face while the other can look in the outby direction. The operator can independently control the field of view, orientation and focus of each camera. Cameras are moved by a hydraulic system that includes rotary actuators and cylinders. Figure 1, a preliminary artist's illustration of a modified Jeffrey 101 TSCM, shows the camera placement; the actual custom-made camera housings are not shown - they are designed to minimize the TSCM's overall height.

Controls and Displays

In order to successfully remote control an operation as complex as mining coal, the operator must be well informed on events occurring at the face. Initial requirements for the controls and displays were determined through an examination of what tasks must be conducted, what information the operator needs to conduct the tasks, and what sensory equipment is available to provide the information.

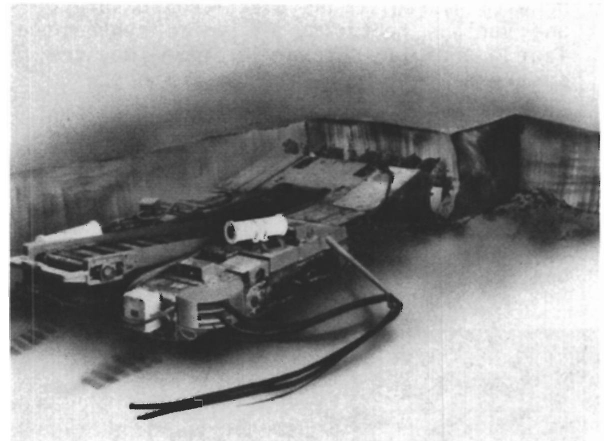

FIGURE 1. - Artist's illustration of modified miner

Because the precise parameters operators use to judge the effectiveness of control are largely unknown at present and may differ among operators, the initial requirements were supplemented with additional inputs. Table 1 shows the sensory inputs provided the operator.

TABLE 1. - Operator Sensory Inputs

Sensory input	Sensor hardware	Display hardware
Vision at face area	Two color TV cameras with zoom, pan, and tilt	Two 9" color video
Relative Positions of auger and tail-boom	Linear potentio-meters	Edgemeters, baragraphs, and voice synthesizer
Sounds from face	Microphone	Panel-mounted speaker
Voice messages	N.A.	Voice synthesizer & speaker
Electrical and hydraulic system parameters	Pressure current & voltage transducer and thermo-couples	Analog meters, "Idiot Lights," and voice synthesizer

As shown in Figure 2, twin 9-inch color video monitors placed directly in front of the operator provide visual information on face events. Auger and conveyor position displays are located around the video monitors, in or as close as possible to the operator's primary visual field. The remainder of the panel space is taken up with hydraulic and electrical displays and various controls. A voice synthesizer, audible through a panel-mounted speaker, provides the operator with selected information during periods of peak visual activity. The miner controls are mounted on a module placed below and at an angle to the display panels. These controls provide the same functions as those normally used to operate the TSCM via a tethered control box.

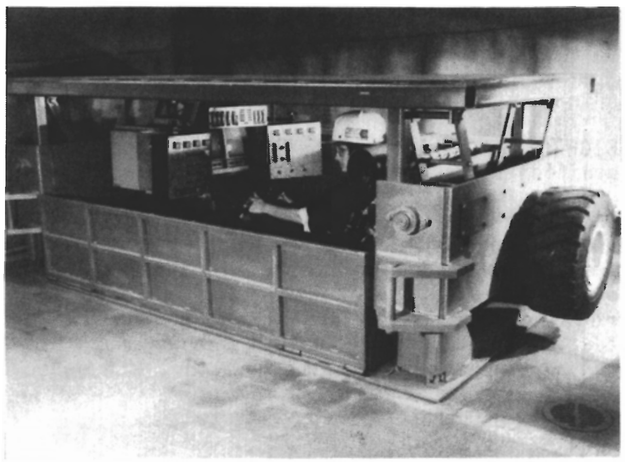

FIGURE 2. - ROS operator station

Electronic Control System (ECS)

The ROS's ECS (figure 3) is built around two computer systems: the HOST, located at the operator's position, and the SLAVE, located on the TSCM [3]. Advantages derived from the ROS's use of computers include: 1) control and sensory data is processed and sent over only 2 wires; 2) a wide range of sensory information is collected from the face area and displayed to the operator through a variety of user-friendly output devices; 3) a voice synthesizer provides selective information to the operator; 4) diagnostic functions are incorporated, simplifying ECS maintenance and repair; and 5) operational and hardware changes are easily implemented. Goals strived for in the development of the ECS included operational flexibility, reliability, low cost, and use of off-the-shelf hardware. The HOST and SLAVE computers continuously communicate with each other. The HOST collects operator input, encodes and transmits it to the SLAVE. The SLAVE controls the TSCM based on confirmed data received from the HOST; it also collects encodes data from machine-mounted sensors and transmits it to the HOST. The HOST decodes the SLAVE data and outputs it to the display devices.

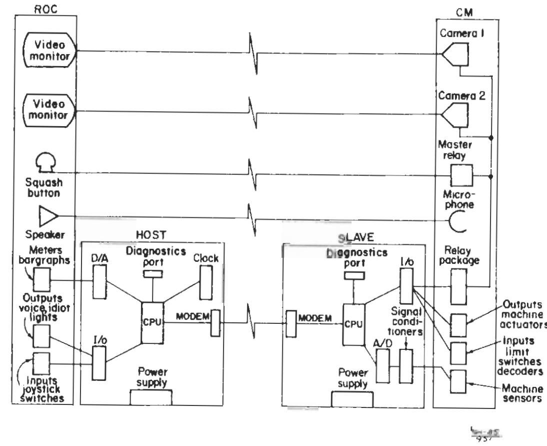

FIGURE 3. - The electronic control system

Computer Communications Protocol

The ROS requires that control signals be sent from the operator station to the TSCM, and face area video and sensory information be sent in the opposite direction. Because a power cable and water hose must extend to the TSCM from the general location of the operator station, wireless communications offered no overall advantage. Therefore, the ROS was designed so that control and sensory signals are carried over a cable run alongside the existing lines.

The communications link between the HOST and SLAVE is critical; data at a rate of 1200 bits/second must pass intact through a single twisted-pair wire contained in the signal cable or dangerous results, such as unintended TSCM motion, could occur. The need for error-free transmission of data between the computers, which may be 500 feet or more apart, is complicated by the extreme amount of electrical noise present in coal mines. This challenge is met by employing short-haul modems (Black Box Co. SHM-NPR), transient suppression devices and special data-encryption and decoding software. If faulty data is received by either the HOST or SLAVE, it is discarded and re-transmission of the data is requested. Several other safety measures are incorporated into the system software to insure safe operation including, if conditions warrant, powering-down of the computers and TSCM. Entire and immediate shut-down of the SLAVE and TSCM also occurs when the large, red SQUASH (emergency stop) button mounted on the control panel is activated by the operator or when the signal cable is severed.

Common Subsystems

Several subsystems are either common or essentially similar to the HOST and SLAVE including diagnostic ports, power supplies, the serial communications link, and an acoustic feedback system. Both computer systems contain a diagnostic port normally used only during testing or initial set-up. If a small hand-held terminal device is plugged into a diagnostic port, system control is relinquished to it. Menu-driven software displayed on the terminal allows an operator to control and monitor most of the ECS functions and the operation of the TSCM.

As electrical transients and power fluctuations are common in mining and intolerable in computer systems, they are eliminated in the HOST and SLAVE by special hardware. Uninterruptible power supplies (UPSs) provide the voltages to run the systems; they are directly powered from gel-cell batteries, which are constantly charged by the line voltage. This arrangement allows even complete line voltage cut-off to be tolerated for time periods of up to 1 hour. TII Electronics Inc. EHVQ-170E-8 switching UPSs are used; they are uncommonly efficient, directly generating multiple DC voltages instead of supplying AC voltages. As a final precautionary step, the UPS inputs are connected to heavy-duty, industrial-grade power line transient suppression devices.

Extraction face sound signals are picked-up by a microphone mounted on the TSCM, boosted by a small amplifier contained in the SLAVE system, transmitted through a twisted-wire pair contained in the signal cable, and presented to the operator through a speaker located in a display panel.

The ECS software was developed using a high-level programming language for the Intel Corp. 8085 microprocessor called PL/M 80. Additionally, an operating system called iRMX/80 (Intel Corp. and Micro-Managers Inc.) was used to provide the capability for real-time multitasking process control.

The SLAVE Computer System

The TSCM-mounted SLAVE system (figure 3) costs approximately $8,000 (for hardware) and is essentially an intelligent input/output port containing a computer. The SLAVE is comprised of two, custom-configured main boards: an Intel Corp. SBC 80/24 card supplies system intelligence and an Analog Devices RTI 711 card provides analog-to-digital conversion. The boards are connected through an industry-standard Multibus I card cage. When a valid command is received from the HOST, the SLAVE outputs an appropriate command sequence that activates relays inside the miner. At precise intervals, the SLAVE also samples data on its input ports and analog-to-digital converter channels, encodes the information, and transmits it to the HOST. All inputs and outputs are optically isolated to protect the computer system. Because the SLAVE is mounted on the TSCM, the electronic components are packaged to fit within a compact explosion-proof housing. Although there was some concern that the system might be endangered by heat building-up in the small box, calculations showed the heat generated by the system's 60 watts power consumption should be effectively dissipated to the outside air.

The HOST Computer System

The HOST system hardware costs approximately $9,000 and is contained on four, custom-configured main boards: an Intel Corp. SBC 80/24 card; an Intel Corp. SBC 116 expansion card; and two ETI Micro Co.'s 8135 analog output cards. The boards are connected through a Multibus I card cage. The primary function of the HOST is to command the ECS based on input received from the operator. Encoded data shipped from the HOST, if valid, cause the SLAVE to exercise the TSCM. The HOST also decodes and checks data packets from the SLAVE. If sensory data is received, it is processed and displayed on up to 48 digital and 16 12-bit analog output devices including "idiot lights," bargraph displays and analog meters. Plug-in modules allow device output drive characteristics to be easily modified.

The HOST is also equipped with a voice synthesizer subsystem; it provides the operator with information on critical events during periods of peak visual loading. The voice synthesizer is a Micro Mint Sweettalker II phoneme-based unit. Ninety-eight project-specific words built into the software are combined as required to form complete messages. HOST components are packaged to maintain a minimum volume. Because the system is located in "fresh air," an explosion-proof housing is not required.

Operator Station

Figure 2 shows the portable control station designed to provide the operator with a comfortable, human-engineered, ground-fall protected worksite. The floor and protective canopy extend against the floor and roof, providing the operator with the largest interior space the seam height will allow, to a maximum of 42 in. Operator ingress and egress are provided through a sturdy horizontal door. The station design accommodates operators ranging in size from 5th percentile female to 95th percentile male. The interior station dimensions are ample and the controls, displays and seat are adjustable through a wide range of comfortable operating positions. The station collapses into a compact, enclosed unit only 24 inches high that is towed to the deployment site. This helps protect the ECS when it is not being used. During towing, a two piece towbar attaches to the main body of the station through pin connectors.

Cable Reel System

Accident analysis showed that an automated system for keeping cable out of the way of the miner and haulage system could greatly improve system safety by minimizing the need for the miner's helper being at the face during mining. Therefore, a 3-section cable reel system was designed to handle the power cable, signal cable and water hose. As depicted in figure 1, the lines are kept away from the equipment by a cable boom attached to the side of the TSCM.

ROS Evaluation

Upon completion of the ROS, initial evaluation and refinement will take place at the Bureau's Mine Equipment Test Facility located at Bruceton, PA by attempting to cut from a block of artificial coal. Required refinements to the equipment, operating procedures, and ancillary systems will be identified, implemented, and evaluated. This phase will include the development of an illumination system to be used when the system is deployed in the field.

Present Status

Evaluations to date have shown the Bureau's ECS to be effective in allowing the activation of the TSCM functions and the reception of video, audio and TSCM performance parameters over a signal cable length of 500 feet. However, the deep mining ROS has not been completed due to delays in securing a TSCM dedicated to the project and the arrival of a unique opportunity. An agreement has recently been reached with a cooperator who supplied a new Jeffrey Model 102HP TSCM to be controlled by the ROS in exchange for use of the control system with a proprietary highwall extraction system. The deep mining ROS system is presently being altered to allow its use for highwall extraction. Although most of the above-described developments are directly applicable to the highwall application, required system modifications include: switching the operator station from a thin-seam underground design to a unit suited for deployment on a highwall bench; deleting the requirement for an automatic cable handling system; re-specifying the camera deployment configuration to gain views to additional areas; and adding the requirement for a system capable of providing guidance information for accurately positioning the TSCM. The current plan is to thoroughly evaluate the ROS in highwall production in the near future, then complete its deployment and assessment as a deep mining system at a future date.

CONCLUSIONS

The remote operation of continuous mining machines 500 or more feet distant from the extraction face appears as an attractive means of significantly increasing operator safety, allowing increased flexibility in selecting mining strategies and expanding the recovery of coal reserves. The Bureau's current ROS developments appear encouraging, but are yet unproven. Potential control problems include that the video information provided the operator will not supply three dimensional perception, and proven coal to roof and floor interface sensors are not available that would increase the probability of the TSCM remaining in the coal seam. However, confidence remains high that future system refinements combined with sensor advancements will allow the developed ROS to mine coal effectively and serve to promote widespread deployment of this technology throughout the mining industry.

REFERENCES

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