A MICROCOMPUTER NETWORK FOR MINING MACHINE CONTROL

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Abstract: This paper details the computer hardware and software integrated to provide computer-assisted control and monitoring of four different coal mining machines. The backbone of each system is a U. S. Bureau of Mines integrated distributed microcomputer control network called BOM/NET. The network provides connections for intelligent sensors and systems that provide for navigation, diagnostics, and computer control. Many different computer systems using various operating systems (including RMX I, UNIX, VXWORKS, DOS and DCX51) have been connected to the network and each have had complete network functionality. A description of the network's integration to Joy[1] 16CM, a Joy 14CM, a Jeffrey 102, continuous mining machines, and a custom built auger machine is provided. The networks for the Joy 16CM, the Joy 14CM, and the Jeffrey 102 have been installed and extensively tested at the Bureau's surface test facility. The Jeffrey 102 system has also been tested in a highwall coal seam. The Joy 14CM will soon be tested underground.

Introduction

An approach of the U.S. Bureau of Mines for minimizing worker exposure to safety hazards inherent in mining is to investigate and evaluate new technology that will move the miners from the immediate area where dangerous tasks are performed. In addition, this technology has the potential to improve the production rate of existing continuous miner's (CM's) by increasing their efficiency and reducing down times. The Bureau's research efforts towards these goals have been enhanced by the creation of a real-time control network. The network enables computer-assisted mining by allowing many diverse computer and sensor systems to interact during the mining process. The work involves numerous research areas including navigation, hydraulic and electrical diagnostics, coal interface detection, and voice control. A bibliography of pertinent Bureau papers related to this research is given at the end of this paper. A commercially available distributed real-time control network called BITBUS (Intel) was chosen as the backbone for the Bureau's network (BOM/NET). BITBUS was selected because of its low cost, reliability, simplicity of operation and maintenance, and availability from a multitude of vendors. Reliability is of major importance in a CM control system because the CM being controlled can weigh up to 50 tons and can virtually rip through anything in it's path. The need for reliability is obvious. Being a distributed network architecture, BITBUS is inherently more reliable than a single computer system because if one computer fails, the remaining computers can still function. It also localizes the problem area thus expedites the diagnostic process. An additional advantage of the distributed architecture is that it has much less difficulty responding to the external environment because there is less for each part of the network to manage. Simplicity of operation and maintenance is required since most mine maintenance and support personnel have limited computer training. The multitude of vendors who can supply BITBUS boards should simplify securing spare parts when failures occur, and the competition should keep the prices realistic.

BITBUS Defined

BITBUS [1] is defined at four levels: electrical interface, data link protocol, message protocol, and application.

The BITBUS electrical interface is based on the RS-485 standard. This standard provides multi-node support over a twisted pair line. The BITBUS electrical interface supports up to 28 nodes on a cable segment, with up to 250 nodes in a fully loaded network using repeaters between cable segments.

The BITBUS data link protocol is based on a subset of the IBM Synchronous Data Link Control (SDLC) standard. SDLC is a proven reliable protocol for interconnecting a master node to multiple slave nodes in a multidrop topology. The standard data link frame format supports node addressing, data link control functions, message transfer and error detection. BITBUS messages are transferred in the information field (see figure 1) of the frame. The information field is defined by the BITBUS message protocol. The data link protocol supports message transfer, with this frame format in two ways: bit error detection in the frame check sequence (FCS) field and sequencing of transfers in the control field. The FCS field contains a 16-bit cyclic redundancy check (CRC) used to detect bit errors on the link. Any node receiving a frame with an invalid CRC ignores it since the cause of the error is unknown. If the error was in the address field, the wrong node or even multiple nodes may have received the message. The master node recovers from this condition automatically by timing out on the slaves response. If this time out occurs, the transfer is automatically tried a second time.

The BITBUS message protocol is defined within the data link protocol (figure 1) and is usually 20 bytes long. It defines the message structure for the information field and the order/reply mechanism for communication between tasks (a task is generally considered to be an instance of a program in execution) on the master node and tasks on the slave nodes. The message format provides an addressing mechanism to route messages to a specific task on a specific processor at a specific node.

Application tasks conform to the message passing protocol. In general these tasks are defined according to the application requirements. One application task however, is defined in every network node. It is called the Remote Access and Control (RAC) task. This RAC task interface allows operation of a BITBUS system without any other specific application task at the slave node. The BOM/NET implementation of BITBUS, however uses the RAC task at every node and additional tasks which will be described later on in this paper.

The Bureau also created a data packet encoding scheme called "BOM/NET protocol" that standardized the interchanging of commands and data between the nodes

[1]Use of manufacturers names is for identification only and does not imply endorsement by the Bureau of Mines.

of BOM/NET. The BOM/NET protocol is defined within the BITBUS message protocol (see figure 1), and employs only the command/response and data fields of a packet. Each of the bytes in those fields are assigned to represent data specific to a node. Most nodes attached to BOM/NET have a unique set of capabilities, each providing some level of control of a device, or each providing some type of data from a sensor package.

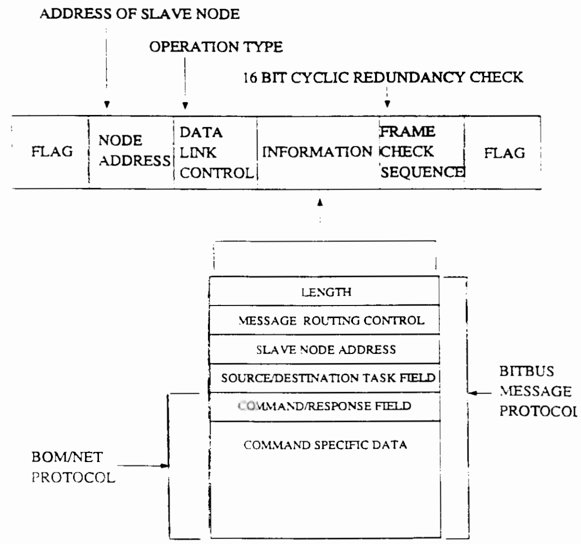

Figure 1. - BITBUS Data Link Frame

Network Hardware

Each node in the Bureau's implementation of BITBUS (called BOM/NET) consists of a microprocessor board that is configured to provide a system function, or it provides a connection to an external computer system that provides some system function. Each BITBUS board is based on a central processing unit (CPU) called the Intel 8044 microcontroller. The 8044 is a member of the Intel 8051 microcontroller family. The 8044 provides a 8051 CPU core and a serial interface unit (SIU). The SIU is an independent processor that provides the SDLC protocol directly in hardware, which off loads the 8051 of all routine communication overhead, allowing it be dedicated to control functions. The two processors communicate through a time multiplexed two-port random accessed memory (RAM) area. This permits both processors to run concurrently at their full clock speed of 12 MHz (instruction cycle is 1 microsecond). The 8044 also includes a small (2 kbytes) real-time multitasking operating system in read only memory (ROM) called iDCX51 which provides the BITBUS message passing protocol and the RAC task which was previously discussed. iDCX51 and the RAC task begin executing as soon as power is applied to the board. The communication speed of the network as it is configured for BOM/NET is 375 kilobit/sec.

BOM/NET Defined

BOM/NET was built to tie together a variety of systems so that they could interact with one another in an expeditious manner while controlling a CM. Each node of the network is generally composed of a single BITBUS board dedicated to one system function or a single BITBUS board that provides a connection (or gateway) to an externally-connected computer system. The nodes, including the externally connected computer systems, are generally classified as a sensor type (a node that provides sensor outputs), a control type (a node that provides control of a device), or a planner type (a node that directs the mining process). Additionally, each is designed to be as intelligent and as self sufficient as possible. This in effect minimizes the amount of data that must be passed between nodes, facilitating the highest level of real-time performance. The network integrated for the Bureau's research testbed (the Joy 16CM) is shown in figure 2.

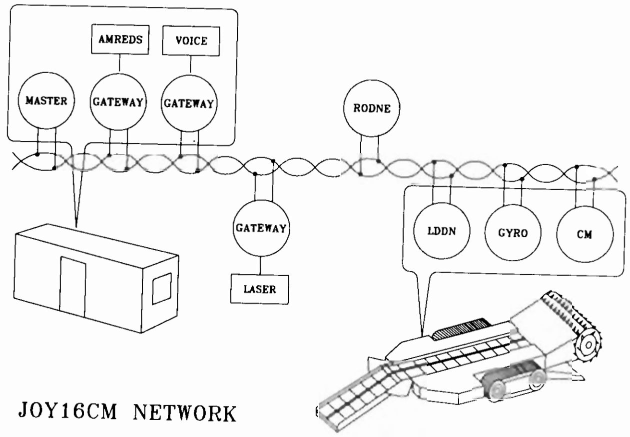

Figure 2. - Joy 16CM Network

On power-up, each of the BITBUS nodes are automatically initialized (including the RAC task) under the direction of their built-in iDCX51 operating system. Then, each nodes built-in application programs begin executing. Some BOM/NET nodes have personalized application tasks, and some nodes are functionally the same as others, except for their numerical network assignment. The specifics of each node follows.

The CM Node

The CM node is a single BITBUS card that provides computer control of all the movable parts of the CM. Additionally, it provides access to all sensor-based machine data. The CM node software tasks include a communications handler, a command processor, an open-loop controller, a closed-loop controller, and a watch dog timer. The communications handler simply provides communications with the master node. The command processor has the function of intercepting all packets received from the network through the communications handler. It extracts the command from the packet and executes it or causes the activation of another task. It also has the responsibility of providing an acknowledgment to the transmitting node. The open-loop controller provides timed control of selected devices of the CM, including the tramming functions. The closed-loop controller provides the movement of selected CM appendages to positions relative to the CM mechanical frame. The appendage position is verified by a sensor that is mechanically linked to the appendage. The final task of the CM node is the watchdog timer task. This task is simply a timer task that toggles an externally connected system status device. If the network locks up or fails for any reason, the externally connected hardware disconnects the power to the CM.

A BOM/NET Gateway Node

A BOM/NET Gateway provides a serial (RS 232) connection from an externally connected computer to

BOM/NET. The software tasks for a gateway node include a communications handler, a serial input task, and a serial output task. The communications handler task only provides communications with the master node. The serial input task accepts data from its serial input port at 9600 baud. The incoming data are tested for validity. If all the data are valid, the serial input task tells the communications handler that it has data to send. The serial output task simply takes from the communications handler any command or data directed to the node from the network, and sends it out the serial port at 9600 baud. It is important to note that all system acknowledgments and command processing end up being the responsibility of the computer system connected to the BOM/NET Gateway.

The Gyro Navigation Node

The GYRO NAVIGATION Node [2] provides the CM with face navigation, employing a gyroscope and clinometers. It is built on a single BITBUS card. Details of this node are documented in the acknowledged reference. The Gyro Navigation Node is one of a collection of face navigation systems that are being evaluated to determine which is the most appropriate and feasible.

The Laser Navigation Node

The Laser Navigation node is a BOM/NET Gateway to a Heurikon computer (using VxWORKS) that is being used to develop a laser-based face navigation system [3], for the mining machine. Details of this node are documented in the acknowledged reference.

The Linear Displacement Device Navigation Node

The Linear Displacement Device Navigation node is a face navigation system [4] that employs linear displacement devices which are attached to the CM and then to a mobile support structure. It is built on a single BITBUS card. Details of this node are fully documented in reference [4].

The RODNE Node

The Remote Operator and Diagnostic Node (RODNE) is a handheld, portable, battery operated BITBUS terminal with a built in LCD screen and keypad. It can be attached to any point along the BOM/NET twisted pair line. Primarily, its purpose is to diagnose BOM/NET system problems, such as individual failed nodes or complete network failure. Secondly, it has built-in application programs that can fully initialize and operate the CM in a menu driven manner, or even in a completely automatic manner.

The Voice I/O Node

The voice I/O node is a BOM/NET Gateway that connects a speaker-dependent voice recognition system [5] (using the DOS operating system) and a voice synthesizer to the network [6]. Algorithms built into the voice recognition system enable a human operator to verbally interact with all the nodes of the network. The voice synthesizer provides voice messages for many system functions.

The AMREDS Node

The Autonomous Mining Research and Development System (AMREDS) node [7] is a BOM/NET Gateway to a Sun Workstation. The Sun Workstation (using the UNIX operating system) serves as a system viewport, a manual command center, an environment for script development, a developmental platform for control programs, a graphical display device for the CM appendage positions during operation, and other functions.

The Master Node

The Master node acts as manager of the network, routing the data from node to node. In the normal integration of BITBUS, the master node sequentially polls each node in the network and processes data according to its program directive. The Bureau's implementation of BITBUS (BOM/NET) locks the master into only handling communications between nodes. This scheme presents an illusion to the individual nodes that makes it seem like every node can communicate to every other node. In reality, however, the one master node is polling each slave node and asking it to which node it would like to talk or respond. The implementation of this scheme requires each slave to dedicate one application task to communications handling.

Operating the Mining Machine Using BOM/NET

Many CM control scenarios can be contrived using BOM/NET. The AMREDS node application software provides many modes of operation including at least Joystick, Simulation, and Scripting. The Joystick mode allows the operator to control individual parts of the CM in a mode very similar to that of the human operator. The Simulation mode allows the operator to construct long scripts of CM functions that are performed sequentially by a wire-frame model of the CM on the operator's local monitor. None of the commands in the Simulation mode ever go to the CM. The primary mode used to operate the CM is the Scripting mode provided by AMREDS. The Scripting mode allows the operator to select from any number of previously created scripts. Once a script is selected and activated, the CM performs the script. Scripts can contain complete power-up and coal production cycles as well as CM shutdown. The scripts access navigation data and insure that the CM is kept on its pre-planned path. The script can be dynamically altered if conditions during the mining process change. The operator of the system can watch the outputs of all the environmental systems of the CM, as provided on the AMREDS monitor, to insure all systems are functioning properly. The operator can stop any active process by hitting any key on the AMREDS node keyboard.

The voice I/O node can also be used to control the CM via BOM/NET. The operator can command individual parts of the CM or execute script files by speaking the appropriate voice command. Other users can use voice control simply by logging on and loading their voice application program. The voice output portion of this node can be made to verbalize anything in its data base. Any node connected to BOM/NET can be accessed by the voice I/O node, and any node can direct the voice I/O to verbalize any canned messages contained within it.

The techniques described in this paper to provide computer control of a CM are not the only modes in which BOM/NET can be used to operate a CM; there are many possibilities. Any node connected to BOM/NET, or any computer connected through a BOM/NET Gateway, has the ability to command or access data from the CM through the CM node. The only requirement to do so, is to make packets conform to the BOM/NET protocol standard. Also, note that it is not necessary to have a fully populated BOM/NET system to automate a CM. In fact, a simplified CM control system could be composed of only one RODNE node and one CM node.

A Highwall Mining System

Demonstration of the inherent capabilities of BOM/NET led to a request by another Bureau group [8] for a customized remote control package for a Highwall Mining System (HMS). The remote control package was required for monitoring and remote control of a Jeffrey 102 thin-seam continuous miner and a 76-m long multiple-unit continuous haulage system. An artist's drawing of the HMS is shown in figure 3. The HMS is controlled from a protected human-engineered operator station that remains outside of the coal seam being mined. The HMS features a laser-based guidance system, dual machine-mounted color TV cameras with dual operator station-mounted video monitors, a complete remote control set for all system functions, bar graph sensor display boards, and a complete suite of Jeffrey 102-mounted sensors for machine position and diagnostics. This implementation of BOM/NET used five BITBUS nodes and the same interface hardware as the previously described implementation.

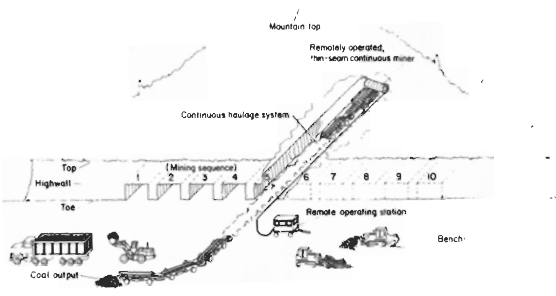

Figure 3. - Highwall Mining System

An Auger-Type Highwall Mining System

Recently, a BOM/NET implementation has been requested for use on an auger-type highwall mining system which will use a custom built Auger Miner (figure 4). The dual auger-type mining machine features on-board auger power provided by large electric motors. Attached to the Auger Miner is a line of dual augers that transport the coal to the outside. Outside the highwall will be an operator control station as well as the coal-handling and auger-handling equipment. This mining system will employ a version of BOM/NET almost identical to the one used on the HMS.

Figure 4. - Auger Mining System

A Field Trial Mining System Using A Continuous Miner

The Bureau has recently developed a computer-assisted mining system using a Joy 14CM. The system employs a BOM/NET system that is almost identical to the system used on the Joy 16CM. Additional nodes will be added to the fundamental network to accommodate expanded research activities (see figure 5). Upon completion of the system (scheduled for July 1990) it will be transported to a production mine where the Bureau developments will be tested underground. These tests will identify which of the Bureau concepts are most mineworthy and reliable.

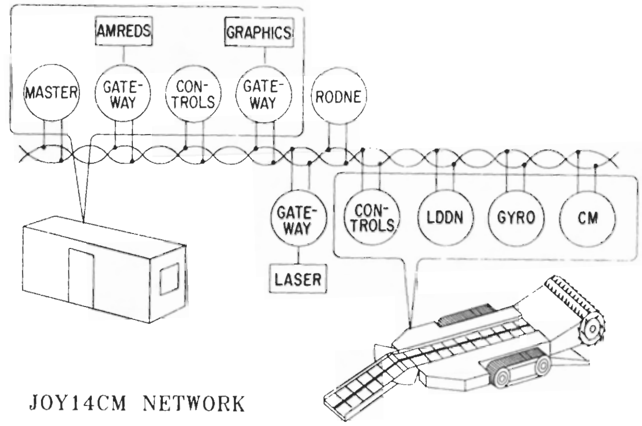

Figure 5. - Joy 14CM Network

Conclusions

The Bureau of Mines has integrated a distributed processing network called BOM/NET that enables a diverse collection of computers and intelligent sensor systems to monitor and control CM's. The installation of the network on a mining machine used for research has accelerated the collection of data and the generation of intelligent navigation and control algorithms. The installation of the network on a HMS has demonstrated its real-time control capability, and its flexibility to adapt to different applications. Each of the cited applications have demonstrated that the distributed processing and control network (BOM/NET) increased the reliability and the functionality of the system to which it has been attached.

All of the BOM/NET systems created generally had the same operational characteristics. They were all constructed from off-the-shelf microcomputers, operating system software, and software compilers. The custom part of each system was the application programs which the Bureau created to suit the needs of the individual mining system.

The various external computers connected through BOM/NET Gateway to BOM/NET systems has shown that virtually any computer system can be made to work in conjunction with BOM/NET with little effort. Conformance to the BOM/NET Protocol is all that is required.

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