RI 9440

REPORT OF INVESTIGATIONS/1992

Underground Test Results of a Laser-Based Tram Control System for a Continuous Miner

By Donna Lynne Anderson

UNITED STATES DEPARTMENT OF THE INTERIOR

MARCH 3, 1849

BUREAU OF MINES

Report of Investigations 9440

Underground Test Results of a Laser-Based Tram Control System for a Continuous Miner

By Donna Lynne Anderson

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

Anderson, Donna Lynne
Underground test results of a laser-based tram control system for a continuous miner / by Donna Lynne Anderson.

p. cm. — (Report of investigations; 9440)

Includes bibliographical references (p. 10).

Supt. of Docs. no.: I 28.23:9440.

1. Mining machinery—Automatic control. 2. Mine railroads—Automatic control. 3. Lasers in navigation. I. Title. II. Series: Report of investigations (United States. Bureau of Mines); 9440.

TN23.U43 [TN345] 622 s—dc20 [622] 92-5712 CIP

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	MHz	megahertz
deg	degree	mV	millivolt
ft	foot	mW	milliwatt
in	inch	r/s	revolution per second
in/s	inch per second	V ac	volt, alternating current
lb	pound	V dc	volt, direct current
MB	megabyte	W	watt

UNDERGROUND TEST RESULTS OF A LASER-BASED TRAM CONTROL SYSTEM FOR A CONTINUOUS MINER

By Donna Lynne Anderson[1]

ABSTRACT

This report documents the status of a laser-based underground guidance system for tracking and controlling the movements of underground mobile mining equipment. This research is part of a multiple project effort at the U.S. Bureau of Mines to increase mine safety and efficiency by developing technology for computer-assisted mining. Guidance systems, which can track and control the movements of underground mining equipment, are essential during computer-assisted mining operations. A continuous mining machine at the Bureau's surface test facility served as the test-bed for initial development and experimentation of this guidance system. Subsequently, a continuous mining machine in an underground mine served as the platform for in-mine experimentation.

The first section of this report includes details of the laser sensors, communication network, and computer hardware. The next section includes experimental results, which show the system capable of accurately tracking and controlling the tram maneuvers of a continuous miner underground. The final section discusses conclusions and recommendations.

---

[1] Electrical engineer, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The U.S. Bureau of Mines is developing the technology for computer-assisted mining systems to increase the health and safety of mine workers and to improve recovery of coal (*1*).[2] Current research focuses on sensor and computer technologies necessary for computer-assisted, remotely supervised operation of a continuous mining machine as it performs two-pass room-and-pillar-type mining. These new technologies will improve worker health and safety by relocating workers from the hazardous working face to a remote, sheltered underground control station. Coal recovery will increase as a greater percentage of minable coal is removed, and more time is spent on production and less on machine idle time.

Reliable and accurate guidance of a continuous mining machine is essential for computer-assisted operation. This report describes a laser-based underground guidance system to track and control the tram maneuvers of a continuous mining machine.

SYSTEM DESCRIPTION

The system uses four Lasernet[3] laser-scanning sensors that report the angular coordinates of two retroreflective targets. The lasers are mounted on two poles located at fixed positions on both sides of the entryway, 25 to 30 ft outby the face. Retroreflective targets are mounted on the tail end of the continuous mining machine (fig. 1).

A real-time microcomputer system requests and processes the angular coordinate information from each Lasernet sensor and does the trigonometry necessary to determine the continuous miner's position and heading (*2*). The microcomputer also executes and controls translational and rotational tram maneuvers.

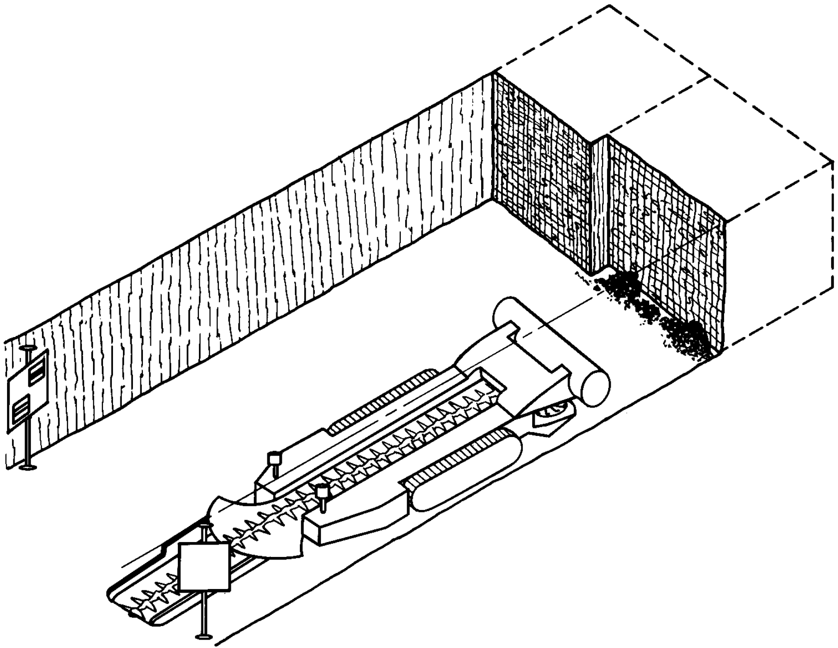

Figure 1.—Conceptual drawing of Lasernet guidance system with targets on continuous miner and lasernet sensors in entryway.

---

[2] Italic numbers in parentheses refer to items in the list of references at the end of this report.

[3] Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

CONTINUOUS MINER TEST-BEDS

A Joy 16CM continuous mining machine at the Bureau's mine equipment test facility (METF) served as the test-bed for initial development and experimentation of the guidance system. The METF also houses a 6-ft-high block of coalcrete, which is a mixture of concrete, flyash, and coal used for testing coal removal operations. A Joy 14CM, in an underground coal mine in West Virginia, served as the platform for in-mine experimentation. Preliminary experiments, run on the Joy 16CM in the METF, helped to prepare for experiments underground on the Joy 14CM.

Both the Joy 16CM and the Joy 14CM were outfitted with sensors for appendage movement of the machines' parts, electrical system voltages and currents, and hydraulic system pressure, temperature, and debris. These sensors, along with the continuous miner hydraulic control valves, tram relays, and other electrically actuated control functions, have been interfaced to a computer. The computer connects to and communicates across the Intel BITBUS distributed control network via a BITBUS node. The BITBUS network supports communications among 16 BITBUS nodes, thereby allowing other computerized mining systems residing on external devices to connect to a node and obtain access to the continuous miner's sensors and functions. The BOMNET protocol, developed by the Bureau, sets the standards for communications between external devices and the BITBUS (*3*).

The BITBUS network and BOMNET protocol let the Lasernet guidance system easily issue tram start and stop commands. The microcomputer system simply writes the appropriate BOMNET protocol packets to a serial port, which is connected to a BITBUS node, designated as node 3. When the continuous miner computer (node 1) receives a tram command packet, it activates the appropriate tram relays. Similarly, the Lasernet guidance system can issue a command to deactivate the tram relays. In this manner, the Lasernet guidance system effects tram control on the Joy 14CM and the Joy 16CM.

GUIDANCE SYSTEM COMPONENTS

Figure 2 shows the major system components used for in-mine testing and evaluating of the Lasernet guidance system. All inby components of the guidance system operate near the continuous miner in the working face area

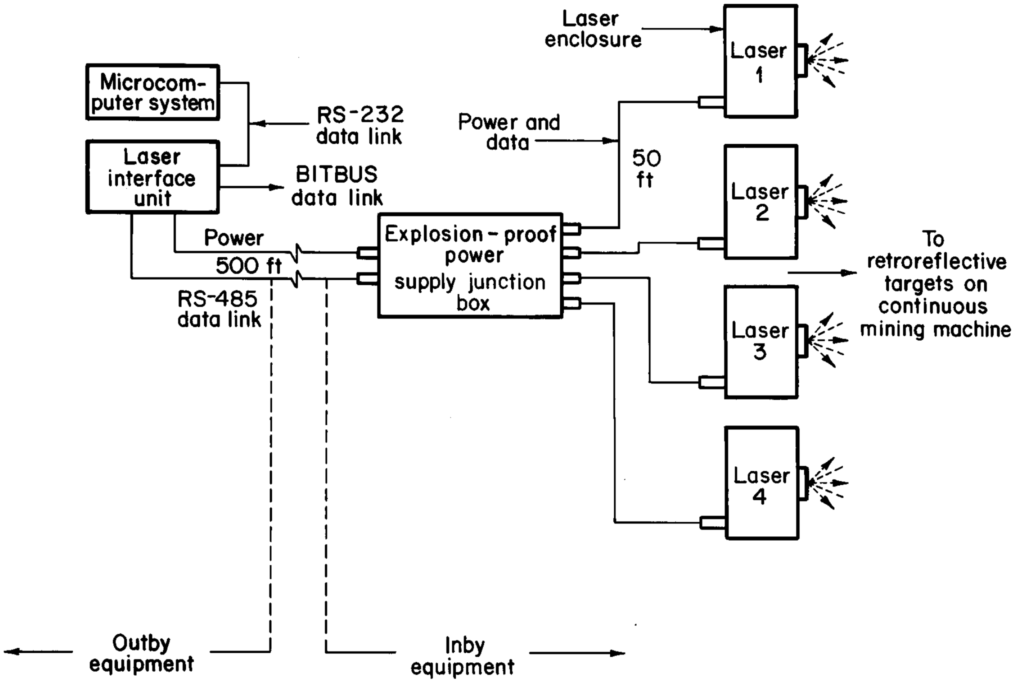

Figure 2.—System components for in-mine experiments.

and are housed in permissible, explosion-proof enclosures. A remote control station houses the outby components. A communications and power cable allow a 500-ft separation between the working face and the control station.

LN-120 LASERNET SENSORS

The laser scanner used in the system is the LN-120/40001 Lasernet (fig. 3), developed by Namco Controls, Mentor, OH. Lasernet directs an eye-safe class 2 laser light source at a rotating mirror. The mirror sweeps a horizontal beam of laser light out the front window of the unit at a constant angular speed of 20 r/s.

The LN-120 model incorporates a 2.0-mW laser tube. It detects targets out to a 35-ft range and has an angular field-of-view of 110°. The targets are retroreflective tape attached to 10-in-diameter, 18-in-tall cylinders. When the Lasernet's beam crosses a target, the beam reflects back to the unit and is detected by a photodetector. A microcontroller in the unit processes the information from the photodetector and determines a raw angle count (RAC), which is proportional to the angular coordinate of the target. The unit returns the RAC's for all targets in its field-of-view upon request from the host computer on a serial data line.

Figure 3.—LN-120 Lasernet laser-scanning sensor.

Extensive tests at the Bureau showed the angular coordinate reports from the LN-120 Lasernet to be accurate to ±0.3°. The accuracy improved to less than ±0.1° after correction of repeatable errors (*4*).

During experimentation at the METF, the Lasernet sensors were mounted on two tripods located at fixed positions on both sides of a mock entryway. Figure 4 shows the setup at the METF. During underground experimentation, the Lasernet sensors were housed in explosion-proof enclosures and mounted on two poles. The poles were at fixed positions on both sides of the entryway, 25 to 30 ft outby the face. Two retroreflective targets were mounted on the tail end of the continuous mining machine.

RS-485 COMMUNICATION NETWORK

The host computer requests and receives raw angular coordinate data from the Lasernet units over an RS-485 communication network. RS-485 uses two-wire balanced differential signals. The longer transmission lines and increased noise tolerance suit underground use. RS-485 also supports multidrop features, which allows all four Lasernet units to be attached to common send and receive lines. Therefore, the microcomputer system requires a single RS-232 serial port, which is tied into the RS-485 network via a Lasernet interface controller.

Each Lasernet unit on the network has a unique communications address included in the request for data. The microcomputer issues a request for data via a serial port. The Lasernet interface controller converts the data to RS-485 format. All units on the RS-485 network receive the request, but only the unit specifically addressed will respond.

EXPLOSION-PROOF HOUSING

The Bureau designed an explosion-proof enclosure (fig. 5) to house the Lasernet sensor for underground experiments. The enclosure is 1/2-in aluminum, welded construction. Mining Controls Inc. (MCI), Beckley, WV, fabricated the enclosure, and the Mine Safety and Health Administration (MSHA) certified it explosion proof. The lightweight enclosure design enables quick and easy positioning. The Lasernet enclosure includes the following features: a frontal lens window made of 1/2- by 2- by 7-1/2-in boro-sylicate glass to allow the full 110° field-of-view; a frontal lens tilt of 12° to prevent lens reflections from causing damage to the Lasernet's photodetector; an Appleton breather plug on the explosion-proof enclosure

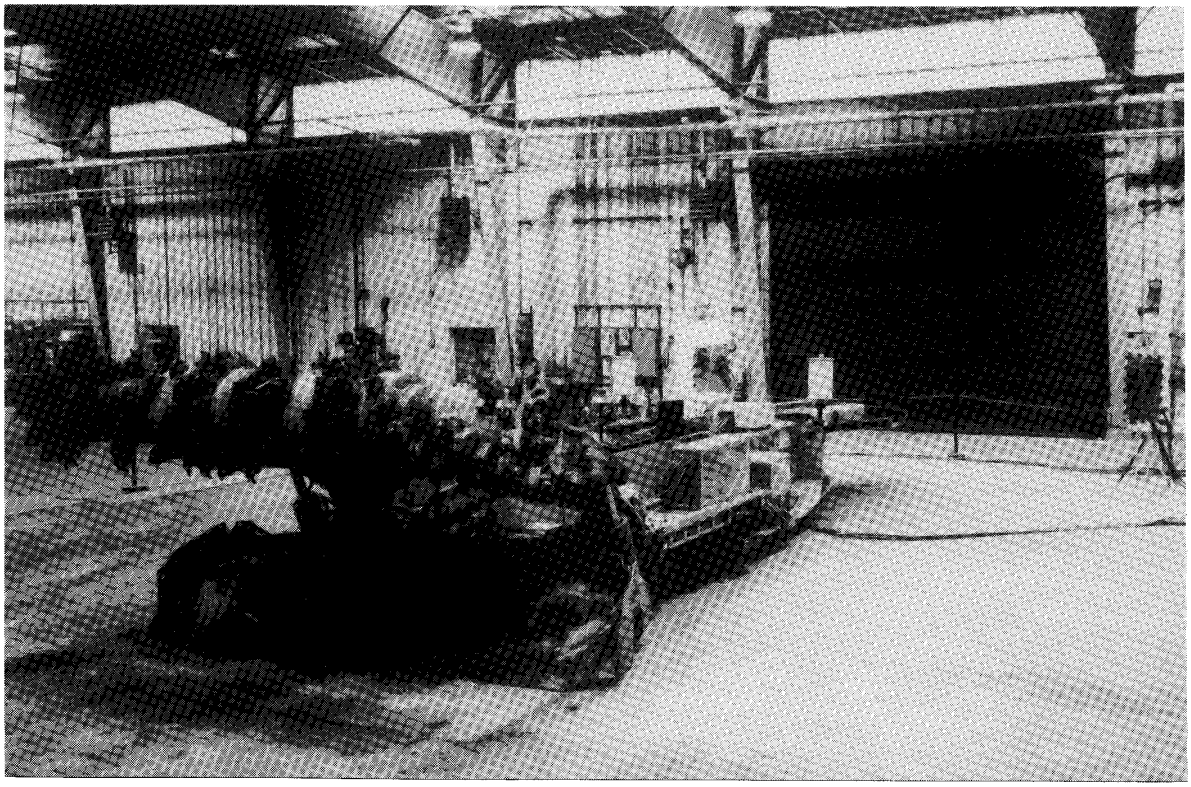

Figure 4.—Experimental setup at Bureau of Mines test facility. Retroreflective targets on Joy 16CM continuous miner and Lasernet sensors on tripods.

to prevent lens fogging and heat buildup; internal shock and vibration mounts to protect the Lasernet sensor; and a top lens window to allow sighting of the optical centerline of the unit for calibration. The power and RS-485 data communication cables exit the enclosure through a packing gland and connect to the Lasernet power supply junction box.

The Lasernet power supply junction box (fig. 6) permits multiple Lasernet sensor connections within the sensor network. The junction box is a standard explosion-proof control box, manufactured by MCI, with internal modifications to Bureau specifications. The junction box is steel construction weighing 60 lb and is movable inby with the Lasernet guidance system. Main power 115 V ac circuit interrupting devices, power control, and electromagnetic interference (EMI) filtering are incorporated into the junction box to comply with MSHA's certification requirements.

The junction box includes a LAMBDA LDS-P-24 linear power supply, which has a maximum of 9 A output at +24 V dc, less than 1 mV ripple, and an input rating of 108 to 127 V ac, 475 W. Power supply derating to +24 V dc, 4.5 A within the enclosure permits ample heat dissipation and cooling for continuous operation. Direct-current (dc) power distribution fusing and line terminations to each Lasernet sensor permit five sensors to be connected. Data line conditioning fuses protect RS-485 data lines within the junction box. The dc power and signal cable to each Lasernet sensor is limited to 50 to 100 ft from the junction box to minimize line losses. The input alternating current (ac) power and signal enter the junction box through 500 ft of cabling within conduit from the outby Lasernet interface unit (LNI).

LASERNET INTERFACE UNIT

The LNI (fig. 7) is a standard 5-1/2- by 19-in rack-mounted portable interface unit. The LNI provides power control, and contains a Lasernet interface controller card and BITBUS network interface hardware. A Lasernet interface controller card converts RS-485 communications to RS-232 data format for connection to an RS-232 serial port on the microcomputer. A BITBUS network interface card and a transient protection module provide a gateway into the BITBUS network from a second serial port on the microcomputer system. Finally, the LNI contains two power supplies: a LAMBDA linear supply with +24 V at 3 A, and a LAMBDA triple output switching power supply with +12 V dc at 1.2 A, -12 V dc at 0.5 A, and +5 V dc at 8 A.

During underground experimentation, the LNI is located with the microcomputer system outby the operating face in fresh air.

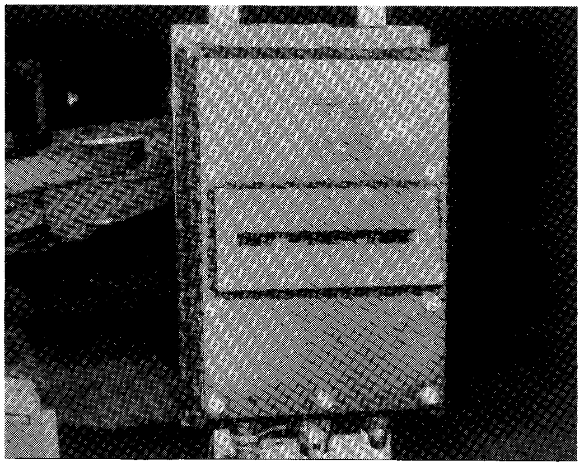

Figure 5.—Explosion-proof housing for LN-120 Lasernet sensor.

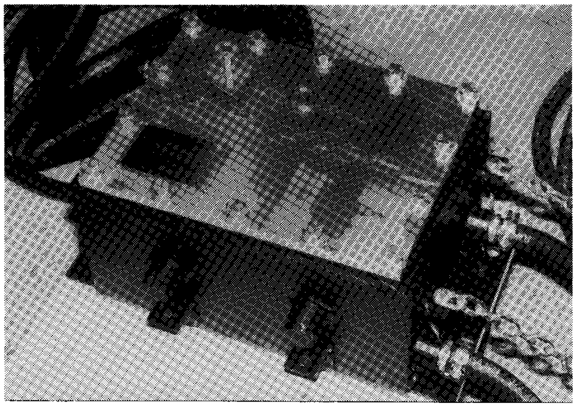

Figure 6.—Explosion-proof housing for power supply junction box.

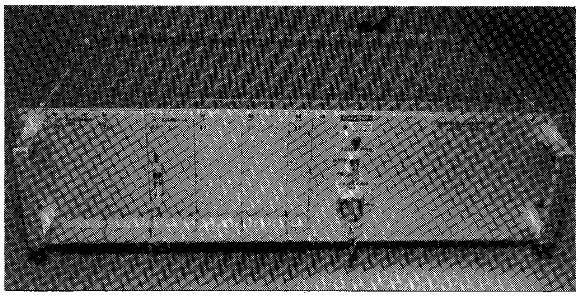

Figure 7.—LNI Lasernet interface unit.

HEURIKON VXS/V2E MICROCOMPUTER

The Heurikon VXS/V2E real-time microcomputer system (fig. 8) processes the Lasernet data, tracks the position and heading, controls the tramming, and handles data requests for the continuous miner. It includes a powerful 32-bit single-board computer that runs VxWorks, a real-time UNIX compatible operating system. The computer includes a 20-MHz 68020-based central processing unit (CPU) board, an Ethernet controller, a 20-MHz 68882 floating-point coprocessor, four serial input-output (I-O) ports, and 4 MB of memory.

The Heurikon-VxWorks system works with the Sun 3-160-UNIX environment. The Sun-UNIX environment provides a high-level software development platform for real-time code development and file management. The Heurikon-VxWorks system provides a platform to run, test, and debug the software for the Lasernet guidance

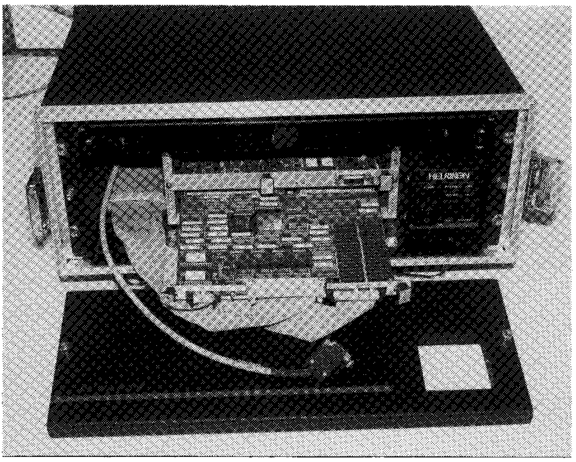

Figure 8.—Heurikon VXS/V2E real-time microcomputer system for tracking and controlling Joy 14CM tramming.

system. During software development, the Heurikon-VxWorks communicates across Ethernet to a Sun workstation. Editing, compiling, linking, and managing files of the real-time software occur on the Sun workstation. However, before testing, the software is downloaded to the Heurikon-VxWorks system across Ethernet. The benefits of using the Heurikon-VxWorks system as opposed to the Sun-UNIX are the implementation of faster and more efficient real-time programming techniques and portability for in-mine use.

SOFTWARE OVERVIEW

The software for the Lasernet tram control system is a multiprogrammed system consisting of several computational and input-output modules. The primary modules include the tracker, the BITBUS data request handler, and the closed-loop tram handler. Figure 9 shows a data flow diagram of these three modules.

The tracker reads data from the Lasernet sensors and places the new position and heading of the continuous miner in a common data store. Updates are calculated as often as five times per second. The closed-loop tram handler accepts tram requests from external devices across the BITBUS network, monitors the updates from the data store, and initiates and controls tram executions. The BITBUS data request handler accepts data requests from external systems on the BITBUS network and delivers the position and heading updates from the data store to the requesting node on the BITBUS network.

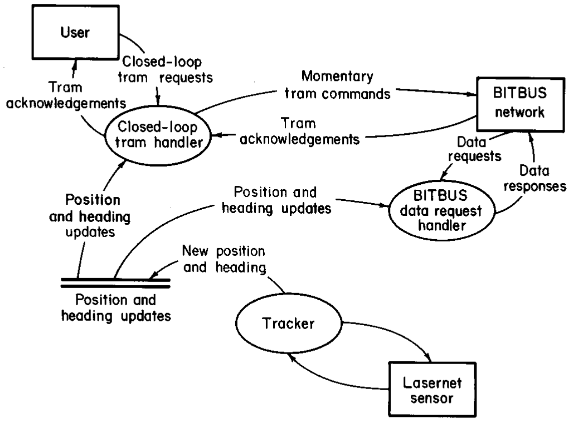

Figure 9.—Data flow among primary software modules.

Other modules include a system initialization routine that creates a system data base at startup time. This routine makes the system easily reconfigurable to suit different guidance tasks. For example, if the operator chose to move the Lasernet unit to another location in the entry, then he or she would enter a new coordinate in the data file, and reinitialize the system, resulting in no reprogramming or recompilation of the software. Also, if a Lasernet unit was removed from the system, then the operator would only enter a new identification address for the replacement unit.

The final feature is a logging facility to collect data during tram experiments. It collects, time stamps, and stores position and heading data to a data file.

EXPERIMENTAL RESULTS

Researchers first took the Lasernet guidance system underground for experimentation in early 1991. The following sections entitled "Reliability" and "Tracking and Tram Control Accuracy" give the experimental results.

Underground experiments involving other computer-assisted mining systems used the Lasernet system to measure tram rates and to track and control the tramming of the continuous miner. To demonstrate potential uses of Lasernet, the "Supporting Experiments" section describes the Lasernet system's involvement in these experiments.

RELIABILITY

The most crucial factor in maintaining the Lasernet guidance system's reliability is keeping the targets in the lasers' view. The lasers have a 110° field-of-view, which easily sweeps the entire entryway. However, the Lasernet sensor has a limited 35-ft target detection range, which reduces the flexibility of the system. It is easy to tailor the experiments to stay within the range; however, for more extensive and practical use of the system, another version of the Lasernet sensor is recommended. Extended-range Lasernet sensors with a 100-ft target detection range have become available since the initial development of this system.

Researchers found another difficulty affecting system reliability during the first experiment. Continuous miner position and heading updates became unavailable when the laser's scanning beam did not cross the targets, i.e., the beam actually scanned above or below the surface of the target. The situation was caused by an unusually irregular floor.

Taller targets increased the vertical tolerance from 14 to 18 in. In addition, two Lasernet units were added to the system. These two Lasernet sensors are mounted 6 to 12 in higher than the original two sensors (fig. 10). With

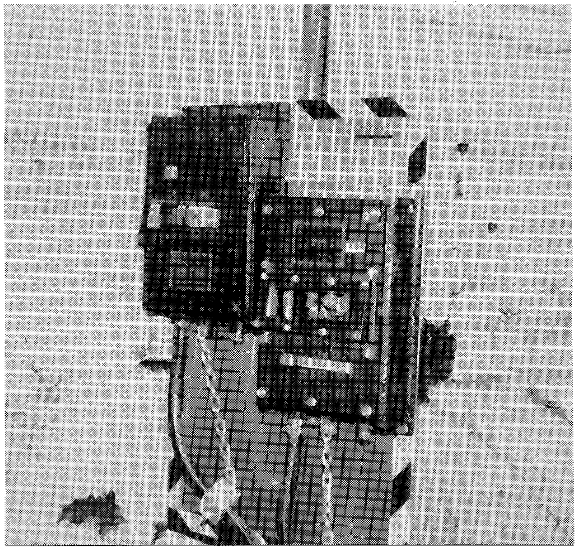

Figure 10.—Two Lasernet sensors mounted at different heights to aid target detection on irregular mine floors.

the two additional sensors and 18-in-tall targets, the vertical tolerance of the system increased from 14 to 30 in. Further underground experiments showed few problems due to vertical intolerance.

TRACKING AND TRAM CONTROL ACCURACY

Researchers accumulated data to determine the Lasernet system's accuracy in tracking the position and heading and controlling the tram maneuvers of the Joy 14CM both at the METF and underground. The goal for a computer-assisted guidance system is to guide the continuous miner through the advancement of a 20-ft cut with less than a 6-in-lateral deviation from the mine plan. A tracking and control system would require a heading accuracy to better than 1.4° (6 in. in 20 ft). The following results of the tracking and tram control experiments show promise toward attaining this goal.

The first experiment showed the accuracy in tracking the position and heading of the continuous miner as it performed a variety of maneuvers underground. After each move, a transit reading verified the XY position and heading (H) of the continuous miner. Table 1 shows some of the transit readings compared with Lasernet XYH. Average errors were heading, 0.4°; X position, 0.65 in; and Y position, 0.2 in.

The second experiment shows the accuracy in tracking and controlling the translations and rotations of the continuous miner. Table 2 shows the results of these tests. The first column shows the desired tram maneuver. The second column shows the actual translation or rotation of the continuous miner, which was calculated using two transit measurements taken before and after the maneuver. The third column shows the translation or rotation measured by the Lasernet system. The final columns show errors that demonstrate the Lasernet accuracy in measuring and controlling translation and rotation. Average measurement errors were 0.62 in translation, 0.32° rotation. Average control errors were 2.05 in translation, 0.72° rotation.

Table 1.—Lasernet tracking accuracy

Transit			Lasernet			Error		
H, deg	X, ft	Y, ft	H, deg	X, ft	Y, ft	H, deg	X, in	Y, in
-2.580	1.026	64.940	-2.382	0.977	64.928	-0.198	0.585	0.143
-3.009	.863	61.747	-2.977	.857	61.743	-.032	.081	.048
-3.224	1.002	64.461	-3.036	.969	64.452	-.188	.405	.109
-3.371	.839	60.990	-3.290	.814	60.981	-.081	.293	.101
-3.371	1.019	64.210	-3.076	.945	64.199	-.295	.885	.131
-16.446	1.106	64.573	-15.907	.995	64.564	-.559	1.331	.106
-5.032	1.177	64.506	-4.710	1.083	64.495	-.322	1.122	.136
-18.072	1.177	64.762	-17.231	1.030	64.753	-.842	1.762	.111
-3.366	1.258	64.700	-3.131	1.206	64.693	-.235	.626	.087
-14.036	1.196	64.028	-13.560	1.113	64.029	-.476	.997	-017
-3.805	1.287	64.796	-3.700	1.284	64.758	-.105	.032	.453
-10.721	1.405	65.855	-10.483	1.368	65.833	-.237	.450	.270
-10.157	.900	62.661	-9.831	.831	62.650	-.326	.821	.131
-.215	1.043	62.599	-.059	1.006	62.591	-.156	.445	.094

H Heading of the continuous mining machine.
X,Y Positions of the continuous mining machine.

Table 2.—Lasernet tracking and tram control accuracy

Tram maneuver	Measurement translation, in		Lasernet error, in	
	Transit	Lasernet	Tracking	Control
Tram reverse 40 in	38.36	38.25	0.11	1.64
Tram forward 36 in	32.61	32.54	.07	3.39
Tram reverse 40 in	41.70	41.69	.01	-1.70
Tram forward 36 in	38.70	38.65	.05	-2.70
Tram reverse 38 in	38.81	38.74	.07	-.81
	Measurement rotation, deg		Lasernet error, deg	
	Transit	Lasernet	Tracking	Control
Pivot right 15°	13.10	12.83	0.27	1.9
Pivot left 12°	11.43	11.20	.23	.57
Pivot right 15°	13.04	12.52	.52	1.96
Pivot left 15°	14.71	14.10	.61	.29
Turn reverse right 10° ..	10.67	10.43	.24	-.67
Turn forward left 10° ...	10.23	9.86	.37	-.23
Turn forward left 7°	6.92	6.78	.14	.08
Pivot left 10°	9.94	9.77	.17	.06

SUPPORTING EXPERIMENTS

Related underground experiments on computer-assisted mining systems used the Lasernet system for its ability to track and control the tramming of the continuous miner. The Lasernet system was an integral part of two experiments to test the first fully controlled, automatic execution of multiple sump-shear cutting cycles. The first experiment used a preprogrammed coal removal script created and executed via the autonomous mining research and development system (AMREDS) (*5*). The second experiment used Carnegie-Mellon University's continuous miner navigation system (MINENAV) software to dynamically plan the maneuvers and appendage commands necessary during a two-pass mining sequence.

The first experiment was an automatic execution of sump-shear cycles via a preprogrammed script of fully controlled continuous miner functions. It used Lasernet to control translational distances of the continuous miner, and AMREDS to create and execute the script of machine commands for coal removal.

The script contained a sequence of continuous miner functions typically used during two successive sump-shear cycles. The script used closed-loop appendage commands, via the continuous miner control computer, and closed-loop tram commands, via the Lasernet system. During execution, AMREDS' script executor followed the script and sent the commands to the appropriate node on the BITBUS network upon successful completion of the previous command in the script.

The experiment initially took place with the Joy 16CM cutting coalcrete in the METF, and then with the Joy 14CM cutting coal underground. In the underground experiment, seven scripts ran in sequence with human involvement limited to pauses to let the shuttle car empty and to issue the script start command. Each sump distance was fixed at 22 in. Table 3 shows the accuracy in which the Lasernet system controlled the sump distance, and also the rate at which the sump was performed. The average error in sump distance was 0.76 in, and the average sump rate was 1.1 in/s.

Table 3.—Tram control and rate during sump

Distance traveled, in	Error, in	Sump rate, in/s
22.35	0.35	1.54
23.06	1.06	1.27
21.88	-.12	1.58
21.20	-.80	.90
21.42	-.58	.87
21.08	-.92	.76
21.42	-.58	1.61
20.28	-1.72	1.12
21.28	-.72	.80
21.17	-.83	.55

A second experiment tested MINENAV software for dynamic planning and execution of a two-pass mining sequence. The MINENAV software includes algorithms for controlling the continuous miner's maneuvering in mine rooms and its appendages while executing a two-pass (box and slab cut) mining sequence. It used the Lasernet system for both tracking XYH and controlling the tram maneuvers of the continuous miner. Lasernet data also characterized the Joy 14CM's tram velocities underground for use by MINENAV.

Using Lasernet XYH updates and controlled translational and rotational maneuvers, MINENAV successfully maneuvered the Joy 16CM through the transition from the box to slab cut. Researchers tested the maneuvering and appendage control required for the actual coal cutting sequence. MINENAV demonstrated the ability to move the Joy 16CM through free space, square up to the coalcrete, and perform a sump-shear cycle in coalcrete.

Researchers performed these same experiments underground with the Joy 14CM. They conducted many successful repetitions of the Joy 14CM maneuvering within a mine room and squaring up to the face, and executed several sump-shear cycles.

CONCLUSIONS

This report described the Lasernet guidance system for tracking and controlling the movements of underground mobile mining equipment. The system was developed and tested at the Bureau's mine equipment test facility on a Joy 16CM continuous miner and in an underground mine on a Joy 14CM continuous miner.

The system successfully and accurately tracked and controlled the tram maneuvers of a continuous miner underground. It employs off-board laser-scanning sensors to report the angular coordinates of retroreflective targets on the continuous mining machine. A real-time microcomputer processes the angular coordinates, calculates position and heading, and controls tram maneuvers of the continuous mining machine.

Results of the underground experiments are promising. The system tracks the position of the continuous miner to an accuracy of less than 1 in, and the heading to less than 0.5°. Tram control accuracies are less than 4 in translation, and less than 2° rotation.

The most crucial factor in maintaining the reliability of the system is keeping the targets in the lasers' view. For more extensive and practical use of the system, an extended range Lasernet sensor is recommended. These sensors have a target detection range of 100 ft, thus greatly increasing the flexibility of the system. Vertical tolerance was also a problem during one experiment on an unusually irregular floor. The employment of taller targets and additional sensors at different heights increased the vertical tolerance to 30 in and resulted in much less difficulty in keeping the targets in the lasers' view. For more extensive use, a mechanical device for vertically sweeping the beam could be added to the sensor to better resolve the problem.

The Lasernet guidance system could be applied to other mining equipment, i.e., shuttle cars, roof bolters. Simple alterations to software could make the system capable of tracking any vehicle with retroreflective targets. Additionally, the Lasernet system could control tram maneuvers of any mining vehicle equipped with a communications interface to electrically actuated tramming functions.

REFERENCES

1. Schnakenberg, G. H., Jr., and J. J. Sammarco. Overview of the U.S. Bureau of Mines Computer-Assisted Mining Research Program. Paper in Proceedings of the International Symposium on Mine Mechanization and Automation. CO Sch. Mines, Golden, CO, v. 2, 1991, pp. 9-29.

2. Anderson, D. L. Position and Heading Determination of a Continuous Mining Machine Using an Angular Position-Sensing System. BuMines IC 9222, 1989, 8 pp.

3. Schiffbauer, W. H. A Microcomputer Network for Mining Machine Control. Paper in Proceedings of the Tenth WVU International Mining Electrotechnology Conference. WV Univ., Morgantown, WV, 1990, pp. 928-935.

4. Anderson, D. L., and J. S. Gbruoski. A Laser-Based Continuous Miner Guidance System. BuMines IC 9288, 1991, 14 pp.

5. Ausefski, D. B. Researcher's Interface Software for Computer-Based Mining System Development and Testing. Paper in Proceedings of the Tenth WVU International Mining Electrotechnology Conference. WV Univ., Morgantown, WV, 1990, pp. 130-133.