A GUIDANCE SENSOR FOR CONTINUOUS MINE HAULAGE

JOHN J. SAMMARCO
U.S. Department of Energy
Pittsburgh Research Center
P.O. Box 18070
Pittsburgh, PA 15236 USA

Abstract—**The U.S. Bureau of Labor Statistics reports that the mining industry has the highest average annual fatality rate (31.9 per 100,000 workers) among all major American industry. To address this, a major research program to reduce hazard exposure of miners with computer-assisted mining equipment was initiated by the U.S. Bureau of Mines.[1] One application involves the manual process of extracting and hauling coal where operators, in the tight confines of a mine, can be struck or caught by mobile machinery. The approach to remedy this problem uses a guidance system on the haulage equipment so that it follows the machine that extracts coal. This, in essence, involves sensor-based docking of the machines. Sensors that can survive the hostile mine environment of dust, methane gas, and water, play the key role. Computer analysis of the mining machine's movements and empirical machine characterizations were conducted to establish operating requirements and spatial limitations to ensure proper loading of coal into the haulage equipment. These data served in the selection of a sensing system. Various technologies such as scanning laser systems and ultrasonic sensors have frequently been used in other applications but were found unacceptable. However, a near infrared (IR) sensor employing active targets met the requirements. The sensor has a nominal 75° conical field-of-view and a range from 0.1 to 18.0 m. For the single target mode, nominal range accuracy was 4.3% at a distance of 3.56 m. Correction algorithms were generated reducing the error to 0.6%. Airborne dust testing showed less than 0.8% accuracy (worst case) degradation at levels exceeding (by a factor of 7.5) concentrations permitted by Federal law. The sensor can track multiple active targets providing five degrees-of-freedom (DOF) measurements. Using four targets, the nominal range accuracy was 0.4% without correction algorithms. A guidance system for the haulage system to follow the mining machine does not exist commercially. Such a system can reduce fatalities and injuries by current haulage mining equipment, and is a viable alternative to current haulage control.**

I. INTRODUCTION

Coal generation plants provide about 60% of our nation's electricity thus making the mining industry a vital part of our national interests. The mining of this coal is quite dangerous for workers. The mining industry has the highest annual average fatality rate of 31.9 per 100,000 workers [1]. Congress mandated the U.S. Bureau of Mines (USBM)[1] to "conduct necessary research and development to improve working conditions and practices . . . to prevent accidents." To address this situation, the USBM initiated a program to develop the enabling technology for a reduced exposure mining system (REMS) [2]. The objectives are to reduce hazard exposure and improve the safety of miners working in the most hazardous areas of the mine. REMS uses computer-assisted machine operation that places operators in the safety of a control center.

II. BACKGROUND

The initial application of REMS involves underground coal mining, specifically room-and-pillar type methods. Currently, we are integrating the extraction and haulage processes so that the coal can be properly loaded from the continuous mining machine into the continuous haulage machine. This task requires the haulage machine to maintain a critical position and orientation as it follows the mining machine.

Positioning mobile equipment is not unique to mining. It is a generalized problem [3]. Research conducted by Sandia Labs concerned sensor-based docking of large payloads [4]. Sensor-based programmable vehicles are used for the transport of hazardous materials or for operation in hazardous environments. Other applications involve military ground vehicle conveying [5] where sensor-based vehicles follow a lead vehicle.

III. CURRENT OPERATING SCENARIO

Coal mining utilizes specialized methods and machines. A common method is known as room-and-pillar mining, in which tunnels are cut according to a predefined manner such as a rectangular grid or a "chevron" pattern. Fig. 1 depicts a small section of this pattern and the equipment used for mining. The main tunnels are "main entries" and the side tunnels are "crosscuts". Main entries are from 5.5 m to 6.0 m wide. Crosscuts are typically 3.3 m. The main entry distances between crosscuts are typically 6.0 m to 12.2 m.

The major stages of operation are initial alignment, advancing the face, turning crosscuts, and backing out of an entry.

A. Initial Alignment: The haulage operator manually positions and controls the haulage machine behind the tail end of the mining machine, using a radio remote control pendant. The objective is to have the tail end of the conveyor placed directly overtop of the

---

[1] This project originated under the U.S. Bureau of Mines Pittsburgh Research Center. The U.S. Congress directed, in Public Law 104-99, 110 Stat. 26 (Jan. 26, 1996), that the health and safety functions of the Pittsburgh Research Center be transferred to the U.S. Department of Energy.

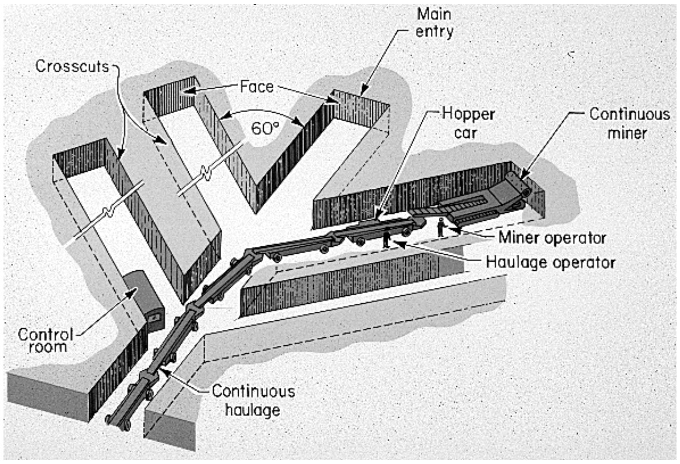

Fig. 1. Room and pillar mining in a cheveron pattern.

hopper car of the continuous haulage machine to ensure that coal will fall into it when the mining process begins.

B. Advancement: The mining machine operator controls the mining machine to cut coal and move the machine forward to cut the main entries and crosscuts of the mine, using a radio remote control pendant. In the development of the main entries, the mining machine takes two cuts to obtain the desired width. Crosscuts are developed after the main entries. Usually the mining machine makes one pass (cut) to advance crosscuts. If a wider entry is required, two passes will be taken. During advancement stages, the haulage operator's job is to maintain the position of the hopper car under the conveyor.

C. Turning a Crosscut: The mining machine begins in the main entryway. To develop the 60° crosscut, the machine must be turned while cutting. This is difficult to do because a considerable amount of positioning and maneuvering of a large mining machine in a tightly confined space is needed. A typical footprint of the mining machine is 3.3 m by 6.0 m. Also, movement is restricted since the haulage machine follows closely behind.

D. Back out: The mining machines must be backed out to begin the next set of cuts. The primary objective is to ensure that the machines do not collide as they back out. The operators must work together to prevent this from happening.

The haulage system used for our research is a Joy 3FCT-4 machine.[2] It is a flexible belt system that winds its way through the mine under control of an operator. The tail end discharges coal onto the section or main belt while the receiving end, called the hopper, is guided by the operator to follow the rear of the continuous miner. Operators are in the dangerous area between the machines where the roof could fall and where they can be struck or pinned by moving machinery. This situation is made more dangerous since visibility is limited by dust, obstructions, and low levels of light. Significant levels of noise, especially during the cutting of coal, can impair hearing and communication between the operators.

IV. REMS OPERATING SCENARIO

The proposed operating scenario employs a hybrid approach combining manual and computer-assisted control. Initial machine alignment (stage 1) is done by manual control since much maneuvering is needed and is most effectively done by humans. Radio remote pendants for the haulage and mining machines are used for this stage. The initial alignment stage is unchanged from the manual method. Manual alignment also enables visual inspection of the machines before operation from the control room begins. The exposures to hazards are less at this stage since the machine is not cutting coal; thus, dust and noise are minimal.

The second part of this hybrid control uses computers and sensors for proper positioning of the haulage system and to assist in control of the mining machine. A sensing system is needed to measure the relative X, Y, and Z position and Yaw of the hopper car with respect to the continuous miner. REMS is implemented from the control room for this phase.

V. REQUIREMENTS ANALYSIS

Computer-assisted mobile mining machines have many of the same requirements as computerized mobile vehicles in other industries. Foremost is the need to determine the machine's position and orientations. This is a challenging problem. For example, the application environment can pose many limitations and requirements on the sensing systems. Underground mining is one such application. It is a dynamic environment of explosive atmospheres and changing physical configurations as new areas are mined. Sensors must not only provide accurate measurement data, but they must operate safely and reliably in the mine.

A. Environmental Requirements:

1) Dust: Airborne dust concentrations vary in relation to the particular mining task. Federal law, mandated by the Mine Safety and Health Administration, sets a maximum level of 2 mg/m^3 for human exposure.

2) Moisture: The sensor will be subjected to direct water contact from splashing or dripping from the roof. Relative humidity can exceed 95%.

3) Explosive Atmosphere: Methane gas is often present in mines along with airborne coal dust. This mixture can present an explosive atmosphere depending on the fuel-to-air ratio and is ignitible by electrical and thermal energy. Therefore, the sensor must be of intrinsically safe design or made permissible.

---

[2] Use of product names is for identification only and does not imply endorsement by the U.S. Department of Energy, Pittsburgh Research Center.

B. Operational Requirements: Computer analysis of the mining machine's movements and empirical machine characterizations established operating requirements and spatial constraints.

Each operational stage needs X, Y, and Yaw data. Additionally, Z data are of use for special situations. For example, it is expected the machines will exceed the loading zone of fig. 2 to handle certain exceptions during the mining process. Z data become useful to detect when the conveyor height is below the top of the hopper car. One can then avoid ramming the conveyor into the hopper car when returning the machines to the loading zone. For example, uneven floors could cause this situation. Under ideal conditions, the vertical clearance is only 22.9 cm. The Z data are not needed for the back out since coal is not loaded.

For each stage, the general operational needs are that (1) the relative positions of the machines are within the proper zone, (2) the tethered cable between the machines is not over extended, (3) the sensor provides position data for all stages.

1) Advancement: Fig. 2 depicts the loading zone for the two vehicles. Empirically, a 15.2 cm trajectory of coal from the end of the conveyor exists and the conveyor swing is 86°. The conveyor is positioned fully up. This affords a 22.9 cm clearance between the top of the hopper car and the bottom of the conveyor. With these parameters (given X, Z, and Yaw = 0), computer analysis sets a maximum separation distance of 121.9 cm. The minimum separation of 15.2 cm provides a "cushion" space.

2) Back out: The most critical item here is to ensure that the machine separation distance does not damage the tethered power cable. The maximum separation is 3.66 m. Exceeding this is possible since the machines move at different rates. The haulage machine reverses at 19.5 m/min versus 16.2 m/min for the mining machine. When backing out of a 12.2-m section, three to four stops of the haulage is needed to avoid excessive separation.

3) Turning a Crosscut: Cutting the 60° crosscut is the most difficult phase of operation to coordinate between the machines. Analysis of such a cut shows a maximum angle between the machines of 41°. Secondly, the maximum length of cable between the two machines is 3.66 m, thus giving a second constraint for turning the crosscut. This is depicted in fig. 3.

VI. POTENTIAL SYSTEMS

Everett [6] and Borenstein [3] present overviews of various sensors for positioning mobile vehicles. These include gyroscopes, RF position location systems, and ultrasonic and optical systems. For example, an active laser ring gyroscope-based system has been produced by Honeywell Military Avionics. It is called the Modular Azimuth and Positioning System (MAPS); prior research [7] investigated it for mining applications. Additional development and refinement of the system [8] has shown this to be a viable method of determining machine position; however, the cost is prohibitive for this application.

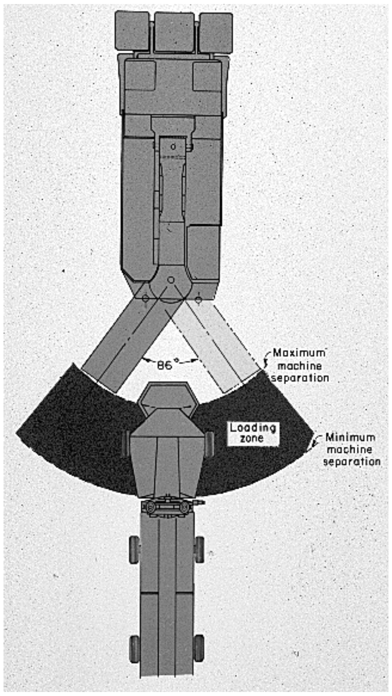

Fig. 2. Loading zone for the continuous mining and haulage machines.

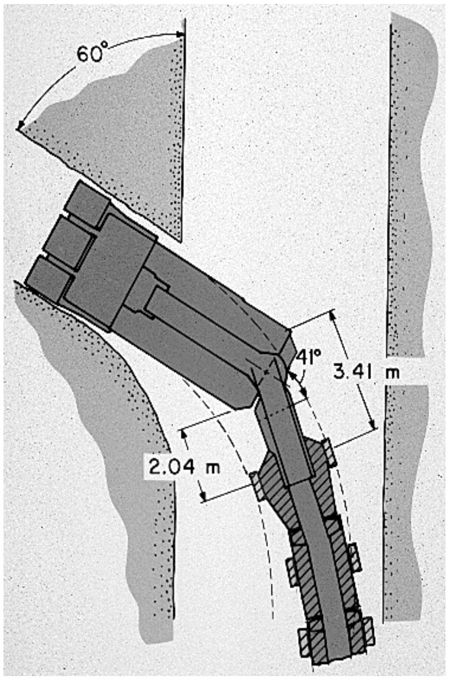

Fig. 3. Cross cut paramaters.

Military applications have also driven the need for navigation technology employing radio frequency (RF) navigation for ground-based or satellite-based systems. Ground-based RF systems exist from Harris and Motorola as described by Everett [6] and Borenstein [3]. Complete system cost can range from $75,000 to $100,000. Harris Technology also offers a ground-based RF positioning system; however, the resolution range, 0.1 to 0.3 m, is unacceptable for the mining application. Obviously, satellite-based systems will not work for underground mining applications although they may have merit for surface mining.

Ultrasonic sensors, ubiquitous in industrial applications, were investigated by the USBM for navigation of underground mobile mine equipment [9]. Results were favorable for distance measurements to mine features such as ribs, corners, and intersections. The application for underground haulage guidance differs in the characteristics of the target, which is the back bumper of the continuous miner. It is a smooth piece of metal, 29.2 cm high and 195.6 cm long. The bottom of this bumper is 38.1 cm high from ground level. From crosscut analysis, two parameters, incident angle and range, become very important in selection of an ultrasonic transducer. The maximum incidence angle is 41°; therefore, the beam angle of the transducer must exceed this value to receive the echo from the bumper. Let the beam angle be 45° and target distance equal 3.66 m. With these parameters, the spot diameter (D) of the ultrasonic beam is calculated as

$$D = 2R.\tan(0.5 \propto)$$

where R = target range
$\propto$ = beam angle

Spot diameter is calculated as 303.02 cm. One quickly realizes the large spot diameter overshadows the 29.21 cm high bumper thus causing target recognition problems. The sensor could possibly read reflections from the walls, floor, ceiling, and conveyor of the continuous miner.

A commercial device for docking is available by Cybermotion. It consists of a vehicle-docking computer and a vehicle-docking head using ultrasonic transducers and infrared (IR) transponders. The ultrasonic beam width of 15° is much less than the 41° needed during the crosscut. Other position systems are posted in frequently asked questions (FAQ) by Dowling [10].

Part four of the FAQ concerns sensors for measuring three or six degrees of freedom. The systems include electromagnetics and scanning optical systems. Electromagnetic devices were found unacceptable when Sammarco [11] documented the difficulties with electromagnetic devices for a mining machine.

Prior work by Anderson [12] investigated a scanning laser system with passive targets for position measurement of a mining machine. Favorable accuracy results were obtained; however, target loss was an initial problem since the pitch of the mining varied considerably due to the uneven mine floor. Another concern pertains to the physical robustness of the scanning mirror mechanism. The sensor in the haulage application would mount on either the haulage machine or the mining machine. Both machines could encounter significant shock and vibration that may become problematic for a scanning sensor.

"DynaSight", a near-IR sensor, was identified as a potential system. A review of the manufacturer’s specifications and subsequent discussions led to additional investigation.

VII. CANDIDATE SYSTEM

The DynaSight sensor is a commercial electro-optic sensor used to measure X, Y, and Z of a target. It is a low-cost system, costing about $2.2 K. DynaSight does noncontacting measurements to an active or passive target. Optionally, the sensor can track multiple active targets with an Active Target Adapter (ATA).

The sensor uses eye-safe IR in the wavelength of 890 nm and has a nominal 75° conical field-of-view. Optionally, the field of view can be factory set for 50°. Measurements are referenced to a fiducial mark on the sensor’s front panel. The coordinate system is right-handed as referenced facing the sensor. This varies from the mine coordinate system where Z and Y are interchanged.

When using passive targets, the near-IR light source is emitted from two arrays separated by a known distance at the front of the sensor. In this configuration, the sensor operates in a retroreflective mode. The range is proportional to the target size where the 75 mm target enables measurements to 6 m. With passive targets, the angular response is about ±45° for the passive targets. Here, target reflectivity increases as the entrance angle increases from 0° to about 40°. Reflectance drops sharply once the angle exceeds 45°; therefore, range and accuracy degrades.

When using an active target, the sensor is set to the "laser mode". Here, IR light is emitted from an active target and received by the sensor. An active target triples the range and doubles the target entrance angles. The sensor can rotate ±35°(given a 70° field-of-view (FOV)) about vertical axis through the sensor’s fiducial mark; the target orientation can vary ±45° for passive targets and ±90° for active targets. Hence, the objects on which the sensor and targets are mounted can undergo a substantial range of orientations relative to each other. This is important to understand since during the crosscut situation depicted in fig. 3, the sensor and the target will be at varying angles of rotation.

The "standard" configuration of the sensor is set for a single active target. With the optional ATA and a second target, calculation of Yaw is possible. This configuration also enables redundancy which is desirable since some targets could be "lost" to failure or be out of the FOV. As the number of targets increases, the update rate decreases. With four targets, the update rate is 16 Hz for each target or a 4-Hz total update rate.

Since the mining machines move slowly, this update rate is acceptable. The maximum machine forward speed was measured at 17.53 m/min when moving in free space on a concrete floor. Thus the maximum machine movement between updates is less than 7.62 cm. The most critical period is during the cutting of the coal where the mining machine moves less than 5 cm/s. Maximum movement between updates is less than 1.3 cm for this period.

A. Sensor Diagnostics: Diagnostic data, for passive or active targets, are given in two forms. First is a visual indication, using a single LED, and second is a digital status word embedded within the sensor's output.

Diagnostics are given for four conditions. They are search, coast, caution, and track. During the search mode, the LED is red. The second mode, called coast, is when the sensor has locked on (found) a target, but has lost it and is attempting to reacquire it. During coast the LED is red. The third mode is caution. For this mode the LED alternates between red and green. During caution, conditions are marginal and target loss is imminent. This caution status can be extremely helpful for the mining application. If loss of a target is imminent, the controller of the mining machine can take alternative action or invoke an orderly stop. The last mode is called track where the signal-to-noise ratio of sensor data is acceptable and target loss is not imminent. During track mode, the LED is green.

VIII. TEST SETUP

Testing of the sensor was conducted in the controlled environments of a lab and in a dust gallery. Lab tests investigated the feasibility of the technology for the mining application. The main test areas concerned accuracy and adaptability for mining.

Lab tests were designed to address the following questions: Should passive or active targets be used and what were the associated accuracies? Next, assuming the sensor's accuracy was sufficient, could the sensor be approvable for operation in an explosive mine environment of dust and methane? The sensor could be approvable if mounted in an explosion-proof (XP) enclosure fitted with an optical window. However, would the optical window impede proper sensor operation and degrade accuracy?

Once feasibility was confirmed, dust tests were conducted. Of primary interest was the effect of airborne dust on accuracy and system robustness. Dust testing was of much interest since airborne dust is always present in mining and can be especially problematic for an optical sensor.

A. Passive target tests: The basic equipment setup consisted of the sensor connected to a PC via RS-232c. The PC ran software written in C to acquire sensor data and to display the output in real time for monitoring. Testing used 22-mm and 75-mm target sizes at distances of 0.31 m, 2.44 m, and 3.65 m. Measurements were taken with targets perpendicular (a target angle of 0°) to the fiduciary mark of the sensor's optical head. Next, the target was rotated to 45° and the tests were repeated. This is of interest since the requirements analysis showed the targets could be at 41° during crosscuts. Target reflectance begins to significantly reduce at 45°, so testing was needed to evaluate operation at this angle.

The next stage of testing involved the repetition of tests at target angles of 0° and 45° while using the optical window needed for the XP enclosure. The window was a 1.26-cm thick fire-polished borosilicate glass with ground and chamfered edges. The intent was to determine accuracy and range degradation due to the window.

Finally, tests involved false target rejection and target obstructions. Multiple sources of false targets existed in this mining application; however, two were of prime concern. They were incandescent lights found on miners caps and mounted at the rear of the mining machine, and retroreflective tape found on machines and miners' caps. Target obstructions could occur as roof material falls or if coal is improperly discharged from the conveyor into the haulage equipment. Of interest was if and how quickly the sensor finds and locks on the actual target rather than the false targets. Operators could also step within the sensor's FOV, causing a target obstruction. False targets and obstructions caused by miners is unlikely since they are to be in the control room while the machines are controlled; however, it is unrealistic to assume human behavior will always be consistent with the design.

B. Active target tests: Testing of the active targets followed the same format as for passive targets. The main changes were with the measurement ranges. The minimum distance was changed from 0.3 m to 0.6 m because the sensor did not provide reliable measurements for distances less than 0.6 m. The maximum distance was increased to 4.4 m to accommodate a distance of 1.2 m from the sensor's mounting location to the front bumper of the haulage machine. In other words, at a machine separation of 3.7 m, the target reference point is 4.9 m from the sensor's fiduciary mark (assuming X, Z, and Yaw = 0).

The first group of tests used a single active target. The next group used the ATA with four active targets arranged in a linear array. Spacing was 30.5 cm between each target; thus, the distance from target 1 to target 4 is 91.4 cm. Target measurements are referenced to the center of the array, located 45.7 cm from the outermost targets.

C. Dust tests: Lab tests for a single active target were repeated within a dust gallery. The sensor was mounted within a dust-tight enclosure fitted with the borosilicate lens. A dust mixture was introduced into the chamber at dust levels starting at 2 mg/m^3. Dust levels concluded at 15 mg/m^3, the maximum obtainable by the test apparatus. For each level of dust, the targets were oriented at 0°, 20°, and 40° relative to the fiduciary mark. These orientations were set for each target distance of 0.6 m, 2.5 m, 3.6 m, and 4.9 m.

IX. TEST RESULTS

A. Passive targets: The initial test results, using a 22-mm target, are shown in fig. 4. The graph depicts a collection of four test conditions of "Y" measurements. Of interest was the sensor's accuracy at varying distances when the target angle was 0° and 45°. These conditions were repeated using the optical window.

In general, errors increased proportionally to distance with the worst case error of 10 cm at a distance of 3.6 m where the target was at 0° and without the window. It was expected that as the target was rotated, errors would increase. Also, errors would increase when the optical window was used. In some cases, such as at 0.6 m, this was true. Overall, no generalized pattern, dependent on the lens or target rotation, was evident through the range of measurements.

At this point in testing, attention focused on false target recognition. False target sources such as a miner's caplamp were introduced into the sensor's FOV while the sensor was "locked on" the actual passive target. At distances of 0.6 m, 2.5 m, and 3.6 m, the sensor did not detect the caplamp. Even if an obstacle obstructed the target, the sensor would, within 0.3 sec, "lock" back onto the passive target and not the caplamp. Tests with reflective tape on a miner's cap showed that when the target was obstructed, the sensor would "lock" on the false target of reflective tape. Thus, the passive target was deemed unacceptable.

B. Single active target results: Tests show that target rotation has a minor effect on the accuracies. Again, error was directly proportional to the measurement distance. Given the consistency of the errors, a second order polynomial was generated for error compensation of Y data for target rotations of 0°, 20°, and 45°. The equation is

$$\text{Compensation factor} = .0003X^2 - .9933X + .7796$$

where the goodness of fit measure $R^2 = .996$.

Applying this compensation reduced errors significantly as seen by fig. 5. The worst case error was reduced from 4.3% at a distance of 3.6 m to 0.6%. Fig. 5 depicts one set of data where the target angle is 45° without a window for the sensor. An analysis of machine operations showed that most of the time is spent advancing the face. This is also when accuracy is most crucial since this is when coal is loaded into the hopper. The analysis gave a machine separation of 2.5 m to 3.7 m for this. The worst case compensated error was 1.4 cm while the worst uncompensated error was 15.2 cm for this range.

C. Dust tests: Dust test results showed a maximum error increase of less than 0.8% with respect to readings at 0 mg/m^3 of dust. This is quite noteworthy since this error was at concentrations of dust more than five times the acceptable level. At the *maximim acceptable* dust concentration of 2 mg/m^3, the maximim error was 0.41%. Dust test results showed very good accuracy at all dust levels; hence, airborne dust is not expected to be a problem for the sensor.

D. Multi-target tests: Next lab tests were conducted using the ATA and four targets. The error data are given in table 1. Two active targets, separated 121.9 m, were used. The measured data values for X and Y were constant where X = 0.5 cm and Y = 1.2 cm. The errors are from raw data. Worst cases and best cases are identified. Average errors at the minimum and maximum loading ranges are shown in table 2.

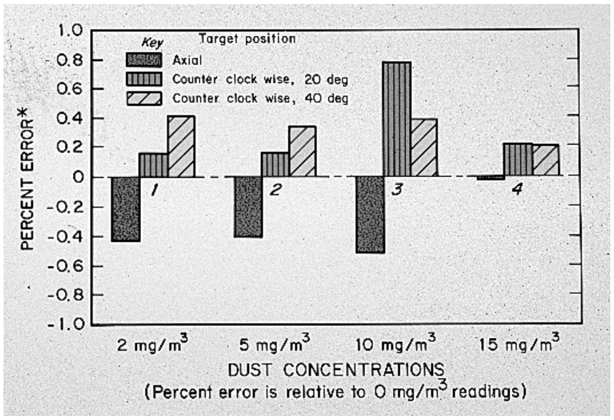

Fig. 4. Passive target results with and without a borosilicate glass window.

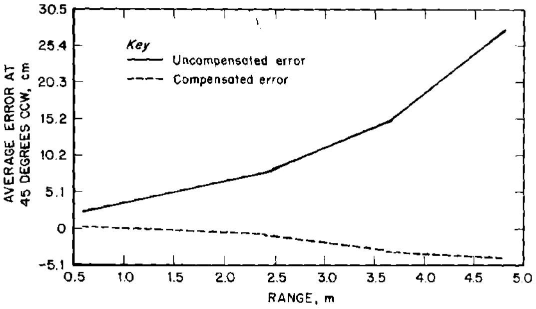

Fig. 5. Compensated errors for a single target oriented at 45°.

TABLE I
ERROR DATA USING THE MULTI-TARGET ADAPTER

Y measured, m	Yaw measured, °	Yaw error, °	X error, cm	Z error, cm	Y error, cm
1.22	0	-1.7	-2.8	0.3	**-10.0**[1]
1.22	20	**6.9**[1]	**4.8**[1]	-0.7	-5.8
1.22	45	NA	NA	NA	NA
2.44	0	-1.6	0.08	**0.0**[2]	0.5
2.44	20	4.8	-2.7	0.1	0.4
2.44	45	**-1.2**[2]	-4.6	0.1	3.7
3.65	0	-1.6	-1.3	**0.8**[1]	2.4
3.65	20	4.8	-3.7	0.8	**0.2**[2]
3.65	45	-1.2	3.8	0.8	2.0
4.87	0	-1.7	**0.0**[2]	0.8	-1.2
4.87	20	-1.9	-2.6	0.8	1.0
4.87	45	-3.5	-4.2	0.8	1.6

NA NOT APPLICABLE
[1]WORST CASE
[2]BEST CASE

TABLE II
AVERAGE ERRORS AT THE MINIMUM AND MAXIMUM LOADING RANGE OF TABLE 1

Y measured, m	Yaw error, °		X error, cm		Z error, cm		Y error, cm	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
2.44	0.67	2.93	-2.41	1.92	0.03	0.04	1.53	1.53
4.87	-2.37	0.81	-2.27	1.73	0	0	0.47	1.47

Significant accuracy improvements are evident in comparisons of the uncompensated single and multi-target error data of fig. 6. As a reference point, Y errors at 3.65 cm (expressed as a percentage of reading) were nominally 0.6% using correction algorithms for single target data while multi-target error was 0.4% without using correction algorithms.

X. SENSOR INTEGRATION

Fig. 7 is the block diagram for integrating the sensor into the haulage system and mining machine. The sensor sends, via RS-233, raw sensor data to a PC/104 single-board computer (SBC). The SBC processes raw target data and sends, X, Y, Z, Yaw, and diagnostic data, via RS-485, to the mining machine control system. The SBC also implements target redundancy and algorithms for tracking multiple targets.

The mining machine control system was developed in the REMS program by the USBM. The controller is used for the crosscut, advancement, and back out of the mining machine. It also is used for coordinated control with the haulage machine. The control system manipulates machine position through forward and reverse translations, pivots, and turns. It also can control the elevation and swing of the conveyor. The scope of control for this system includes the haulage machine. Thus, the control system can send control commands to the haulage system to manipulate position and orientation.

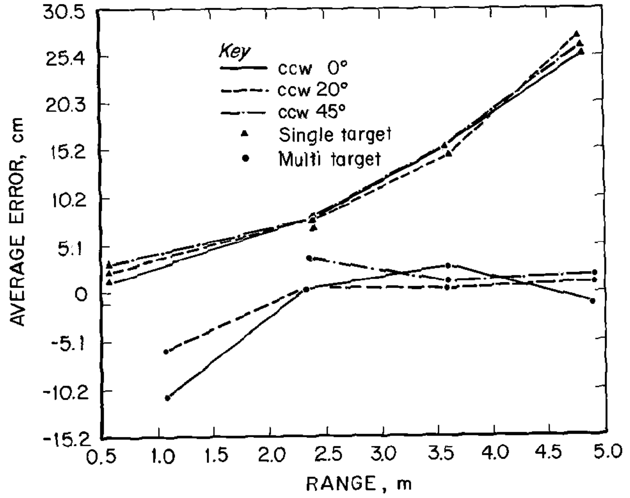

Fig. 6. Single and multiple target comparisons.

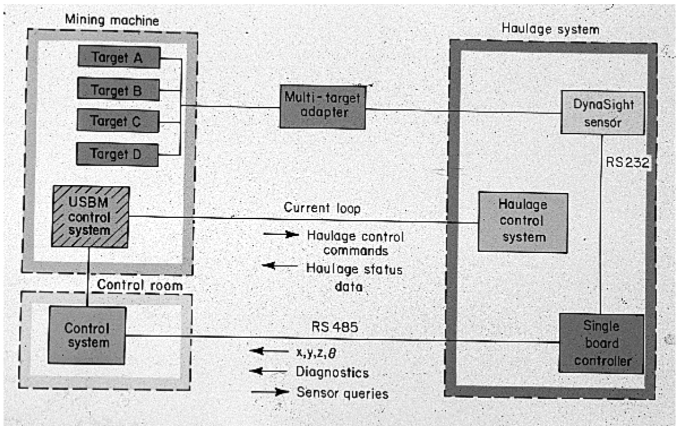

Fig. 7. System block diagram.

XI. FUTURE WORK

The DynaSight sensor holds much potential for applications in mining as evident from the testing and analysis described. Next, long-term field testing in actual mining conditions will be conducted. Of interest is sensor operation during cutting periods when machine vibration is maximum, and secondly, how well the sensor operates as dust accumulates on the optical lens and active targets. Also, packaging modifications are desirable such as repackaging the sensor's optical head to improve accuracy and eliminating the active target tether to simplify the system.

XII. CONCLUSIONS

The implementation of REMS for integrating the extraction and haulage process could reduce the potential of miners being struck or caught by moving machinery. This requires a system to determine the haulage machine's X-Y position and Yaw. The DynaSight sensor, with an active target, is the best candidate based on accuracy, excellent operation in airborne dust, false target rejection, and cost. In comparison to a single active target, the multi-target option for the sensor is the most desirable for mining applications since this mode has target redundancy, improved accuracies, and reduced hardware.

REFERENCES

[1] U.S. Dept. of Health and Human Services, Fatal Injuries to Workers in the United States, 1980-1989: A decade of surveillance. DHHS(NIOSH) No. 93-1085, August 1993.

[2] J. J. McClelland, R. F. Randolph, G. H. Schnakenberg, Jr., and R. S. Fowkes. Safety Breakthrough - Reduced exposure mining systems (REMS). BuMines Special Publication SP-26-94, 1994.

[3] J. Borenstein, H. R. Everett, and L. Feng, "Where am I? Sensors and Methods for Autonomous Mobile Robot Positioning, 1995.

[4] W. D. Drotning, Automated waste canister docking and emplacement using a sensor-based intelligent controller. Sandia National Laboratories, SAND91-0558, 1992.

[5] D. Gage and J. B. Pletter, Ground vehicle convoying. SPIE, v. 852, Mobile Robots II, 1987.

[6] H. R. Everett, Sensors for mobile robots: Theory and application. A. K. Peters, Ltd., 1995.

[7] J. J. Sammarco, Field evaluation of the modular azimuth and positioning system (MAPS) for a continuous mining machine. BuMines IC 9354, 1993.

[8] W. H. Schiffbauer, Navigation and control of continuous mining systems for coal mining. To be presented at 1996 IEEE-IAS Annual Meeting, San Diego, CA, October 5-10, 1996.

[9] W. H. Strickland, and R. H. King, Characteristics of ultrasonic ranging sensors in an underground mine. BuMines RI 9452, 1993.

[10] K. Dowling, Robotics: comp. robotics frequently asked questions. 1995. Available as a hypertext document, http://www.frc.ri.cmu.edu/robotics-faq.

[11] J. J. Sammarco, Mining machine orientation control based on inertial, gravitational, and magnetic sensors. BuMines RI 9326, 1990.

[12] D. L. Anderson, "Position and heading determination of a continuous mining machine using an angular position-sensing system. BuMines IC 9222, 1989.