PRELIMINARY SPECIFICATIONS FOR ROBOTIC APPLICATIONS IN MINES

A Presentation for the Second Conference on Robotics in Construction June 24-26, 1985 at Carnegie-Mellon University

by

Robert H. King

Acting Head, Mining Engineering Department

Colorado School of Mines

Golden, CO 80401

INTRODUCTION

The future of the American Mining Industry is being threatened by profound global changes in the cycle of supply and demand. The industry's problems include:

- Declines in sales and profits
- Large debts and debt service burdens
- Escalating transportation problems
- Rigorous and expensive safety and environmental regulations
- Depletion of easily accessible high-grade deposits
- Increasing competition from low-cost international producers
- Significant substitution of alternative materials
- Considerable replacement of raw materials by recycled products

As a result, several mines have closed, many have reduced personnel and work schedules, and many are operating marginally at present with the daily threat of temporary or permanent closure. These problems have resulted in considerable media attention; for example, the Business Week article about the "Death of Mining". Doom and gloom forecasts are all too prevalent in the industry today. Rather than accept the premise that the industry is dead, or dying, solutions need to be found that will improve profitability and international competitiveness.

One solution, among several, is to improve productivity by applying robotic equipment. In addition, significant health and safety benefits can be realized. Because the industry is aware of the benefits of introducing high-technology, several research efforts by companies and the U.S. Bureau of Mines have been undertaken (King, 1985). However, recent research funding reductions in the mining industry and the increased pace of robotic technology advancement require renewed efforts to participate in high-technology research programs.

Since productivity, profitability, and safety benefits for underground coal continuous mining were identified in an earlier publication; this paper will discuss preliminary specifications for mining robotic equipment (King, 1978). To limit the length of the presentation , the underground coal, continuous, room-and-pillar mining method will also be used as an example system in this paper; however, the major conclusions and recommendations of the previous work and this paper are applicable over a range of mining methods.

SIMILARITIES BETWEEN MINING AND CONSTRUCTION

Since this conference attracts an audience from both the mining and construction industries, it is important to review the similarities between the main features of the industries before discussing robot specifications. Warszawski (1984) presented an excellent tabular summary between construction and manufacturing that is extended to mining in Table 1.

It is obvious from this comparison that many similarities exist between mining and construction. As a result, many companies are successful at both. These similarities extend to the benefits and problems of robotic technology application. In general, the following requirements apply to both mining and construction robots.

mining and construction robotic equipment must have:

- a high degree of mobility
- extensive sensing capability
- significant artificial intelligence
- robust and rugged components

capability of lifting and moving heavy objects
high reliability in a wide range of environments
simple maintenance requirements
the ability to perform in limited spaces

However, there are some obvious differences between mining and construction that will affect robot specification, design, and use. For example, because mining is an extraction process, it generates more harmful dust and gasses than construction. In addition, even though a mine requires a high degree of mobility on site, most mining equipment is not transported from site to site as often as construction equipment. While mines handle typical construction materials such as lumber, blocks, pipes, and electrical hardware; they also move large amounts of ore, coal and/or waste rock. Even though construction sites have significant geomechanics concerns, they are significantly different from those in mining when robotic equipment design is considered.

MINING TASKS

Even though differences exist, the similarities are such that developments in basic technology are applicable to both industries. Since the focus of this paper is the underground coal, continuous, room-and-pillar method, a brief summary of tasks performed in the present system is necessary.

A summary of the typical cyclic activities that take place where ore or coal is produced underground is: extraction, loading, hauling, supporting the roof, and advancing ventilation. Table 2 expands these activities into elemental tasks for continuous room-and-pillar mining and shows the general mine support tasks that may occur in other areas.

The miscellaneous element was included for intermittent tasks such as general mine construction, installing and maintaining track and trolley wire, transporting equipment between sections and establishing new mining sections. A detailed description of each task can be found in King, 1978.

THE MINE ENVIRONMENT

Mine robotic equipment must function reliably in a very harsh environment. The underground mine environment varies with that at construction sites, while surface mine environments may be similar to construction. In addition, the underground coal mine example does not accurately reflect the entire industry since temperatures, for example, vary from -40°F to 140°F in surface mines, but the lowest temperature in the underground mines is 40°F (Dayton T. Brown, 1981). However, underground equipment may experience severe temperature shocks as it enters and leaves the mine.

Another significant variation is in solar radiation levels. Approximately 94 watts/ft^2 can be expected at a Florida surface mine. The spectral distribution is 3% ultraviolet, 44% visible, and 53% infrared.

The altitude for all mines may be up to 10,000 feet, whereas underground mines may be as deep as 10,000 ft in the U.S.

During normal operations in underground and surface mines, shocks are 5-10 g's. However, short duration shocks of up to 43 g's have been recorded. Similarly, the worst case vibration levels are 4 g's up to 2000 Hz.

Dust, in large quantities, is common in underground and surface mines. Underground, the greater than 10 micron size particles may concentrate up to 10 mg/m^3. Dust may be distributed in air with velocities from 50 to 2000 fpm.

Moisture results from ground water seepage and intentionally applied water sprays for dust suppression. It may be in quantities similar to a heavy, steady rainfall. Humidity is also a problem. It may exist up to 100% in some mines in combination with high temperatures. The water in mines may be very corrosive with a PH as low as 3.

Electromagnetic interference exists in most mines in the field range of 100 Hz to 1000 MHz. Magnetic noise is dominated by 60 Hz and 400 Hz harmonics from the power system. Furthermore, transient spikes of 10X line voltage occur.

PRELIMINARY PERFORMANCE SPECIFICATIONS

The present performance specifications for continuous mining machines could be used as a guide for a robotic machine. Table 3 gives information for a Joy 12CM11.

Table 3. Joy 12CM11 Specifications

Capacity = 8-12 TPM
Ground bearing pressure = 24.5 psi
weight = 87000 lbs
length = 32 ft 10 in.
seam height up to 12 ft
machine height = 52 in. with canopy
cutting width = 9 ft 6 in.
tram speed = 15 fpm sump
= 30 fpm low
= 55 fpm high
motors = 455 hp

However, the specifications for a robotic version should not be constrained by the existing equipment. Continuous miners are used extensively for development of longwall mining sections. Longwall is safer, more productive, and produces a lower cost per ton than continuous mining. But continuous mining development constrains longwall operation and increases the overall cost of the mine product.

Consequently, high technology should be applied to improve the system, not duplicate it. The reason for reduced continuous miner productivity does not lie in the machine itself, but with the operating system. Therefore, to be effective, robotic technology must be applied to the entire cycle of activities.

An example of production section equipment and crew is shown in Table 4. The production from the miner is constrained by haulage, roof bolting and other functions as shown in Table 5.

If production is to be increased, the elemental times and production might change, as shown in Table 6, in an evolutionary or revolutionary manner. The data in the table was the result of analysis from introducing:

An autonomous, low-cutting-rate (4 tpm) continuous miner that could advance one to two crosscut lengths (90 - 180 ft) in a straight line without requiring human intervention. The machine is teleoperated for turning crosscuts and changing places.

An autonomous continuous haulage system patterned after the existing bridge or flexible conveyor.

Autonomous roof bolting machines either mounted on the miner frame or small satellite units.

Remote control station for personnel.

An integrated system management capability using artificial intelligence.

A work schedule of limited human intervention and consequently reduced hazard exposure.

In general, robotic technology may improve production by eliminating delays and making the entire system more continuous. The cutting rate of the continuous miner used in this example was lower than the Table 3 specifications, in an attempt to improve reliability and introduce a greater probability of matching haulage and roof support capacity.

Further detailed analysis is required to forecast the cost effectiveness of a robotic system. The increased capital investment should be estimated, and production goals for a suitable payback period should be established before extensive research costs are incurred.

CONCLUSIONS

The statements regarding the auxiliary system constraints to continuous miner productivity made in this paper are widely recognized in the mining industry. Numerous attempts have had limited success in removing those constraints. The author believes that application of new artificial intelligence developments and autonomous equipment research have potential in solving the problem.

However, if robotic equipment research is to be successful in realizing its potential to accomplish the objectives of reducing costs, improving productivity, and increasing safety; it must consider the entire mining system, and not be constrained by studying a single element, or by the specifications of existing machines. In addition, robotic equipment may change the entire complexion of the present mining process.

REFERENCES

Dayton T. Brown Inc., 1981, "Environmental Test Criteria for the Acceptability of Mine Instrumentation", Final Report on U.S. Bureau of Mines Contract J0100040.

King, Robert H., 1978, "An Evaluation of Automation and Romote Control in Continuous Coal Mining", Ph.D. Thesis in Mining Engineering at the Pennsylvania State University, University Park, PA.

King, Robert H., 1985, "Summary of Advanced Technology Research in Continuous Underground Coal Mining Methods 1946-1978", to be published in Energy and Mineral Resources, Colorado School of Mines Press, Golden, CO.

Warszawski, Abraham, 1984, "Robotics in Building Construction", Carnegie-Mellon University Report R-84-147.

Table 1. Comparison of the major features of manufacturing, construction and mining

Manufacturing	Construction	Mining
All work performed at one permanent location	Work dispersed among many temporary locations	Work dispersed among many locations, some permanent, but most temporary
High degree of repetition and standardization	Small extent of standarization. Every project has distinctive features	Moderate extent of standardization in coal mining, small extent in metal mining
Small number of simplified tasks necessary to produce a typical product	Large number of tasks requiring a high degree of manual skills necessary to complete a typical construction project	Large number of tasks requiring a wide range of skill levels
All tasks are performed at static work stations	Every task is performed over a large work area with workers moving from one place to another	Some tasks performed at stationary locations. Most tasks performed at temporary locations. Many tasks require mobile equipment.
Work place carefully adjusted	Rugged and harsh work environment	Rugged, harsh, and hazardous work environment
Comparatively stable work force	High turnover of workers	Moderate turnover of workers in todays economy
Unified decision making authority for design, production and marketing.	Authority divided between sponsor, designers, local government, contractor and subcontractors.	Unified decision making authority

Table 2. Elemental Tasks

1. cutting and loading;
2. face haulage;
3. section roof control;
4. face ventilation -- advance and retreat;
5. section ventilation -- outby the face;
6. electrical trailing-cable handling;
7. moving the power center;
8. relocating the conveyor belt;
9. conveyor belt cleaning;
10. rock dusting;
11. roof testing;
12. methane measuring;
13. inspecting by the mine examiner, fireboss or foreman;
14. supply handling;
15. transporting fresh and drainage water;
16. servicing equipment;
17. maintaining equipment;
18. conditions monitoring;
19. cleaning spillage and roadways (other than belts); and
20. miscellaneous.

Table 4. Example of Production Section Equipment and Crew

Quantity	Item	Quantity	Crew
1	Continuous Miner	1	Continuous-Miner Operator
1	Clean-up Loader	1	Loading-Machine Operator
2	Shuttle Cars	2	Shuttle-Car Operators
2	Roof Bolters on the Miner	2	Roof Bolters
1	Auxilliary Face Ventilation Fan	1	Ventilation Man
1	Power Center	1	Utility Man
1	Rock-Dusting Machine		
1	Trickle Duster		

Table 5. Example of Continuous miner time elements and production

Time Element	Average Minutes per Shift
Production Time	
Cutting & Loading	70
Necessary Time	
Place Change	45
Shuttle Car Changeout	0
Mantrip	50
Lunch	30
Fireboss Inspection	15
Prepare to Start	20
Prepare to Leave	20
Other Necessary Time	30
Delays to Production	
Bolt Delays	60
Maintenance Delays	75
Ventilation Delays	10
Outby Haulage Delays	20
Other Delays	35
	480
Total Shift	
Raw Tons per shift	310
Clean Tons per shift	250

Table 6. Proposed Automated-Mine Production and Production-Shift Time Elements

Time Element	Average Minutes Per Shift Stage I	Stage II	Stage III	Stage IV
Production Time				
Cutting & Loading	95	140	200	230
Necessary Time				
Place Change	25	30	45	55
Shuttle Car	40	0	0	0
Mantrip	50	50	50	50
Lunch	30	30	0	0
Fireboss Inspection	15	15	10	10
Prepare to Start	20	20	15	10
Prepare to Leave	20	20	15	10
Delays to Production				
Other Necessary Time	25	25	20	15
Bolt Delay	30	20	10	0
Maintenance	75	75	75	75
Ventilation	10	10	10	10
Outby Haulage	20	20	10	0
Other Delays	25	25	10	15
Total Shift	480	480	480	480
Raw Tons per shift	380	560	800	920
Clean Tons per shift	310	460	660	750