Surface Mining: Main Research issues for Autonomous Operations

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1 Abstract

This paper presents the author's view on the main challenges for autonomous operation in surface mining environment. A brief overview of the mine operation is presented showing the number of components that needs to interact in a safe, robust and efficient manner. Successful implementation of autonomous systems in field robotic applications are presented with a discussion of the fundamental problems that needs to be addressed to have this technology accepted in mining operations.

2 Introduction

Resource based economies will be facing enormous challenges to remain competitive in a global economy. Mine operations are in most cases located in isolated areas making the relocation of personnel very expensive. Furthermore, this situation is becoming more difficult these days since the deposits discovered are much smaller and the life of the mine may not justify the establishment of new towns. The development of field robotics automation is one of the key factors to address this problem. Automated and autonomous systems are beginning to make a significant appearance in different areas. At the simplest level, such systems act as adjuncts to manned vehicles in providing, for example, location information, collision warning, or driver enhancements. At a more complex level, a number of automated machines for hauling, excavation and loading are being introduced and have had some success mainly in underground mining. At the level of a complete mine, it is possible to envision the fusion of positional, geophysical information into a complete mine "picture" and the subsequent use of this to exert overall coordinated control of individuals, vehicles and systems in the mine. The overriding strategy in the development of the digital mine is the concept of "systems of systems". This concept is pervasive in military and other complex systems communities. It recognizes that the ultimate system, a mine in this case, is composed of many different system units, and that these in turn are composed of yet smaller systems. The key to the successful management of the overall mining system is to understand how component systems need to work together and to devise technology and procedures to allow these elements to function as part of the overall system. Specifically in mining, the mine site consists of personnel, vehicles and machines that have to be allocated according to the best geophysical knowledge available, market conditions and financial constraints, Figure 1. Figure 2 shows a simplified model of the mine operation. Once the mine pit is prepared the trucks are loaded with different type of machines and the ore is moved through haul roads to the crusher. It has been estimated that the cost of haulage accounts for $40-50\%$ of the surface mine operating expenses [1] . The real time availability of information such as ground conditions, orebody morphology, grade distribution will make high fidelity simulation of systems essential to rapidly adapt to the dynamics of the actual circumstances. The full integration and analysis of systems will also be of fundamental importance to develop the concept of distance mining. It is now conceivable to integrate machine monitoring and control, geophysical sensing and remote image analysis with different levels of resolution sensors into a global database. This information can then be accessed from different locations around the world to minimize the number of personnel at the site. This will require the development and deployment of different technologies into the mine environment. This paper presents discussion of where automation have worked in the past, a vision for the mine in the future and some steps that will need to be follows to enable full autonomous mines.

Fig. 1. Mining equipment involved in a mine operation

Fig. 2. Simplified view of a mine operation

3 Mining Automation

3.1 Future of Surface Mining

Due to the uncertainty on the state of resources actual surface mining operations needs to operate in a conservative manner to be able to satisfy customer requirements and shareholder profit. In the future Surface mining operation will be:

- **Product Driven:** customers will demand specialized product that meets their individual requirements.

- **Flexible:** they will employ operations methods focussed towards swings as opposed to base line productions.

- **Agile:** capable of operating in a market where orders change quickly or even daily basis.

Mine sites will use whole-of-mine plans and will view planning as a dynamic and reactive process. The management system are likely to take the form of very comprehensive spatio-temporal database representing the actual physical structure of the mine: geology, resources, pit layout, road structure etc., [3]. They will dynamically revise and evaluate operating decision based on comprehensive costing models and forecasting tools. Will use accurate real time monitoring technologies to track their performance against projections, feeding back information to the planning process. These changes will be facilitated by the emergency of technology that deliver focussed, high quality timely information that enables performance against production targets to be accurately tracked. These new technology will also reduce the variability in the operation making the equipment more reliable and the production more predictable. This operation will require breakthroughs in resource characterization. It is expected that new tools will be available to enable the resources to be mapped (seam thickness, structural properties, compositions) to submeter accuracies. Excavation equipment will have on-board sensing used to provide real-time visualization ahead of the mine face. These sensors will be part of the mine network and their data will be used to update and validate the resource map in real-time. The mine plan and mine status will be contained in an environment that contains up to the minute whole-of-mine data including mine topography, resource maps, equipment deployment etc. The information will be maintained and updated automatically from a variety of sources including fly-over images, sensors mounted on mobile platforms, dynamic resource maps etc. This information will be visualizable anywhere in the site making the mine operation safe and efficient.

3.2 Where has mining automation worked in the past

There are a number areas where automation has been successful in the mining area. These examples are in rail haulage, process control type applications, conveyor systems and to a certain extend in underground drilling. An example of a process type application is shown if Figure 3. In this case a laser is used to track the position of the wagon and control the bin door to load the coal. The system also recognizes the locomotive and establish the communication with the train driver to synchronize the whole operation.

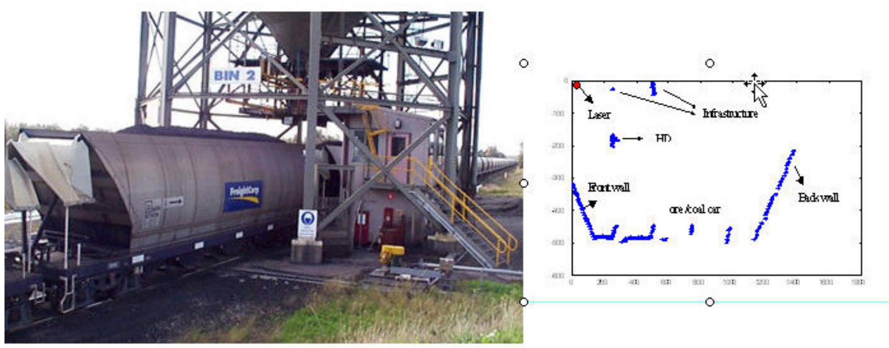

Fig. 3. Automatic coal loading application using a laser to detect the position of the wagon

There are other new automation application that are much more sophisticated. These include:

- **Autonomous LHD's**
- **Autonomous Underground and Surface trucks**
- **Autonomous straddle carrier**
- **Automated underground face drills**
- **Longwall automation**
- **Dragline swing automation**
- **Autonomous drilling / rock recognition**
- **...**

Among them the most advanced implementation of autonomous system in underground environment is the LHD automation. Figure 4 shows an early version of an automated LHD. The system navigates in the mine by looking at the walls of the tunnel[2]. It has been demonstrated in 1999 and has been operating in various mines since then. Figure 5 shows a commercial implementation of a free range autonomous straddle carrier [6]. The system allows the straddles to move and stack containers from the quay, into the holding yards, onto vehicles and back to quay cranes with cm accuracy. Both systems work in and area where only autonomous systems operate.

Fig. 4. Automated LHD

Fig. 5. Autonomous Straddle carriers operating in Fishermans Islands, Australia

3.3 Hard problems in mining automation

The unit operation that offers the greatest potential for reducing operating costs in surface mining is haulage. The enabling technologies (navigation, truck control, and collision detection) for autonomous haul trucks (AHS) exist in a semi-mature form and prototype AHS integrating these technologies are known to been developed and tested by at least two of the major manufacturers (Komatsu and Caterpillar). The Komatsu system has the capability to navigate a haul route, dump automatically to hoppers or to the ground, and work with some type of loading equipment. The system leverages off several mature technologies, notably the global positioning system (GPS) and inertial navigation systems (INS) for navigation and millimetre-wave radar and laser systems for safety and collision detection. The system is designed to operate in an area with only autonomous trucks.

Nevertheless there are no actual deployment of these system in any mine in the world. Although automation of large machines is already well advanced this technology is limited by the extent to which automated trucks interact with other equipment and by the system integrity that can be incorporated at a reasonable cost. The last statement requires further clarification. All the previous successful autonomous application have the following characteristics:

- **Structured environment**
- **Well defined automated task requirements**
- **There is a need for the solution**
- **Site willing to adopt the new technology**

- **Simple / Robust technology**
- **No interaction with manned machines**

On the contrary the environment where surface mine haul truck need to operate are:

- **Rugged environments(Dust, moisture, extreme weather conditions**
- **Dynamic and often unpredictable**
- **Unstructured and often defined by geology**
- **Difficult to sense and costly to incorporate integrity**
- **Difficult to build simple, effective and robust models**
- **Significant interaction with manned machines**

In general the challenges in mining automation become increasingly formidable as the level of autonomy increases. Automation technologies will only flourish after the evolution of the real-time, whole-of-mine, information systems takes place. Such systems are virtually mandated where autonomous equipment is to interact with other equipment (manned or autonomous) by providing the framework for managing the interaction. Without such a system, equipment interactions need to be eliminated or very closely managed to the point where the limitations outweigh the benefits of automation. Removing the driver means that the functions he or she performs beyond driving need to be performed automatically. These consist largely of monitoring the overall health of the truck including detecting, isolating, and reporting faults and monitoring the environment, e.g. the quality of the road surface. Most of these activities are not formal tasks, but rather occur as part of the driver's broader state of awareness. For this to happens we need new sensors and perception technology capable of determining the actual state of the world under all possible environmental conditions. For example, an autonomous truck should be able to determine the different states of the road as shown in Figure 6 and adjust the driving conditions accordingly to optimize the use of the truck.

One of the main issues in autonomy is integrity. That is the design of autonomous system with enough sensory redundancy in the frequency domain to detect any possible fault [5]. This problem can be seen in Figure 8 where a millimetre wave radar has been designed to be able to monitor the state of the face under the presence of smoke / dust. Perception and interpretation will also be an area of significant importance in mining applications. Figure 8 shows an example where the 3-D radar data is used to extract the position of nearby vehicles next to shovel based of known models of potential resources in proximity.

3.4 The next step

The most significant advances in the next few years are likely to come through tools such as operator assists and partial automation that develop and prove

Fig. 6. Typical road state under different environmental conditions

component technologies while building deeper understanding and awareness of the equipment operating and issues leading full automation. This is very important since mine operation are essentially high risk. Each year, hundreds of mining haulage accidents occur, resulting in a significant number of deaths and injuries as well as costs through replacement, repair and downtime. Many of these accidents are due to microsleep events that are a manifestation of operator fatigue. This issue has been researched extensively and it has been demonstrated that humans will have a significant number of microsleep occurrences per shift when they are required to work at night [4]. During these events the driver loses control of the truck for a short period of time. This is becoming a more important issue where larger trucks are introduced without a corresponding enlargement of haul road widths. Most mine managers are now more aware of these problems and are starting to take a more active role in supporting the development of new operator fatigue systems. Figure 9 presents a variety of accidents involving haul trucks. Some of these accidents are due to the driver falling asleep and veering of / or crossing the centre of the road. Others are due to poor visibility of smaller objects or vehicles in close proximity to the truck. This section presents two examples of aiding equipment that can prevent many of these accidents. The first problem is addressed

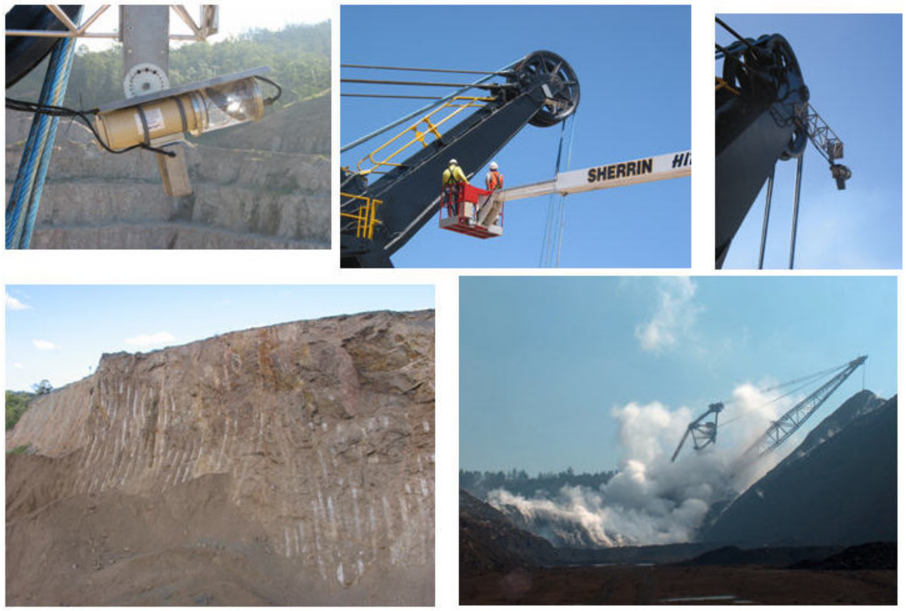

Fig. 7. Millimetre Wave radar installed in a rope shovel

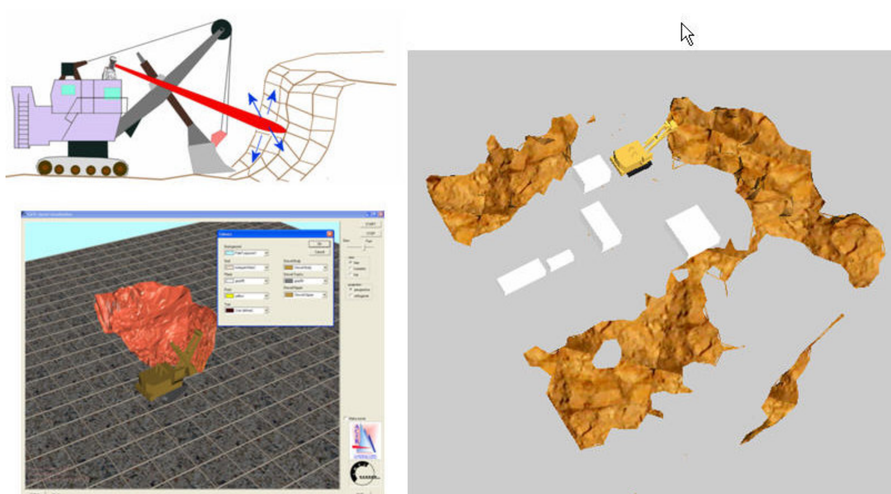

Fig. 8. Automatic object recognition

with an approach that uses a scanning lasers mounted on haul trucks. These sensors monitor the position of a truck with respect to a series of PVC poles embedded in the berms along the length of the haul road. This information is used to define a valid corridor for the vehicle, Figure 10. If the truck wanders outside this corridor an alarm is triggered. This system has been fitted to a fleet of 15 Komatsu 730E trucks, Figure 11, and has been in routine use at Alcoa's Huntly and Willowdale mines for more than a year. The system has proven to be reliable and is regarded by these mines as an invaluable tool to allow large trucks to be used safely on relatively narrow roads [7]. It has the obvious additional safety benefit of helping to prevent accidents caused by operator fatigue.

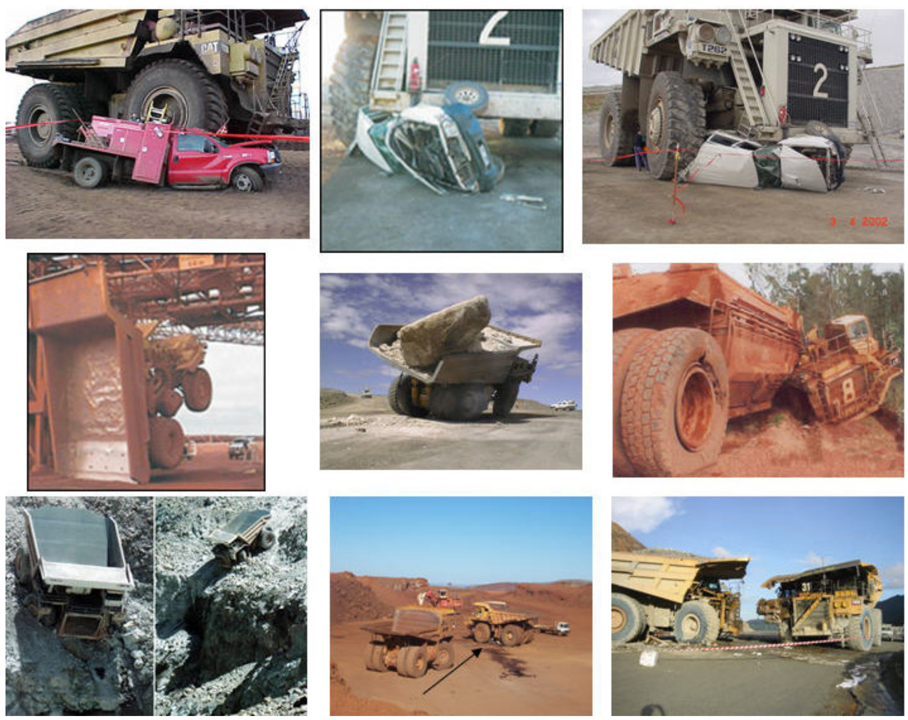

Fig. 9. Haul Truck accidents

The second problem can be addressed by using a wireless network and GPS sensors to detect the position of other vehicles in the area of operation, Figure 12. The area of operation will be a function of line of sight of the antennas of the agents in proximity. Once the agent becomes part of the network they will know the position and velocity of all the other agents in the proximity area. A protocol implemented in the Haul Truck system will generate a series of alarms according to the threats. The installation of this technology has also

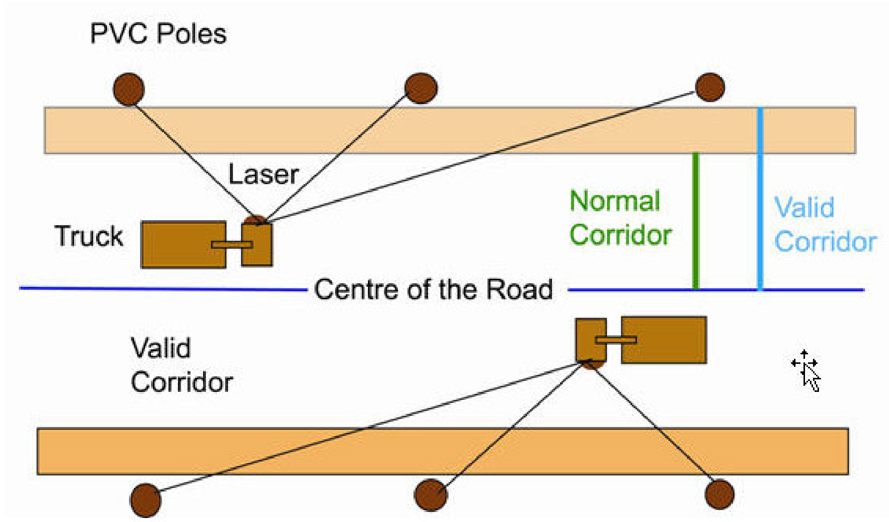

Fig. 10. Basic principle to determine the position of the truck in the road

Fig. 11. Truck fleet and a truck retrofitted with a laser based tracking system

the potential to be used to move information around the mine. It is easy to see that by using the haul trucks we can move information from the different parts of the mine and download it to base stations installed in frequently visited areas like the crusher. This information can then flow in the internal intranet of the mine and can be used for other monitor and optimization purposes.

4 Conclusions

This paper presented some successful autonomous application of field robotic in structured mining type environments. It also presented an overview of some

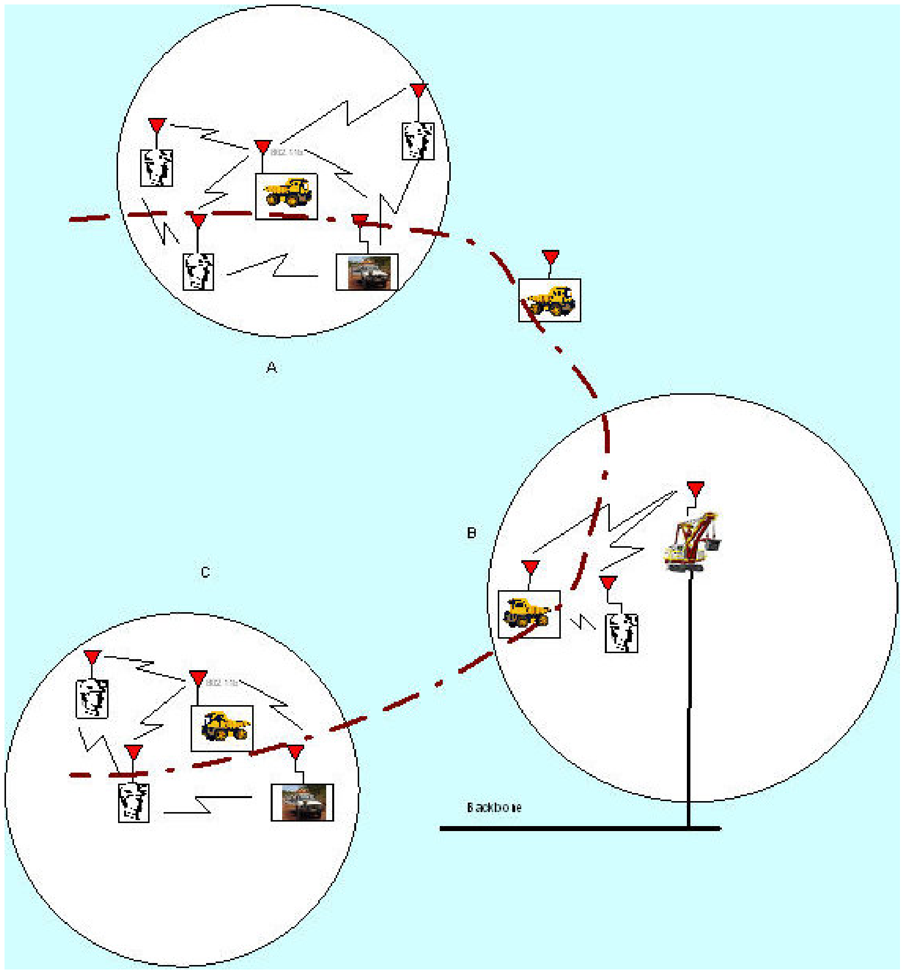

Fig. 12. Local ad-hoc network based proximity system

of the important challenge faced in mine automation and the areas where progress is needed to enable fully autonomous mining.

References

1. Mukhopadhjay A(1989) Selection, maintenance, and relations of various parameters for off-highway hauling tires. In: Off-Highway Haulage in Surface Mines, Ed. Golosinski, Sraje, Balkema, pp 153-159.
2. Roberts J, Duff E, Corke P, Sikka P, Winstanley G, Cunningham. Autonomous control of underground mining vehicles using reactive navigation. In: Proceed-

ings of IEEE Int. Conf. on Robotics and Automation, pages 3790-3795, San Francisco, USA.
3. Lever P, McAree R ACARP (2003) Project C11054 Open-cut Automation Scoping Study.
4. Williams S, Asleep at the wheel March 2002, World Mining Equipment, incorporating World Mining and Mining Equipment International.
5. Scheding S, Nebot E, Durrant-Whyte H High integrity Navigation using frequency domain techniques IEEE Transaction of System Control Technology, July 2000, Vol 8, Iss. 4, pp 676-694.
6. Sukkarieh S, Nebot E, Durrant-Whyte A High Integrity IMU/GPS Navigation Loop for Autonomous Land Vehicle applications", IEEE Transaction on Robotics and Automation, June 1999, Vol 15, No 3, p 85-95.
7. Nebot E, Guivant J, Worrall S, Haul Truck Alignment Monitoring and operator warning system To appear in Journal of Field Robotics (2006)