Application of robotics in underground mining industry – a review

Since mining is one of the hardest and hazardous activities there exists a need of robotics. Reason for deployment of robots in mines are mainly associated with increasing operating cost, need for faster production and health and safety of miners. Though many mining companies in order to improve the productivity and miners safety usually provide training sessions for miners regarding safe and better work practices and uses better machine but this existing conventional approaches are providing diminishing trends of returns. The mining industry is now relying upon robotics and automation to improve productivity and safety by reducing human activity whereever it is impossible for human being to work or even survive without exposing to life threatening danger like charging of blastholes/laying explosives, stabilization of mine roof after blasting, mining in accessible areas where it is not possible to extract earlier. This paper gives an overview of different areas of application of robotics in underground mines.

1. Introduction

Industrial robotics made great contribution towards automation of manufacturing processes which have resulted in increased productivity, reduction in production cost and improved product quality. Most of industrial robots perform simple and repetitive task like pick and place, machine loading and unloading, welding etc. But mining industry is highly dynamic and complex and under such circumstances industrial robot does not perform well. Fatality statistics for underground mining operation worldwide clearly indicates that most fatality arises from inaccessible areas of mine where it is difficult for mining personnel to even work or survive and in these areas regular systematic monitoring and maintenance operation is difficult as a result of which human operators have no control over such unwanted happenings [1,2]. Therefore, application of robotic technology is best and reliable methods for improving productivity and reducing hazard to mining personnel. At the inception stage, most of industrialist wanted to automate the entire mineral extraction process using robotics. However, same is considered to impractical and highly expensive process based on the technological constraints as on date. We are probably a few decades away from having fully automated mines. Automation was introduced in coal mining industry by application of mechanical haulage devices, conveyors and shearers on coal face in early 1950s [3]. If all mining equipment could be made automated without any human interference or attention then it would be possible to access unworkable seams and enhance productivity and reducing human exposure to hostile work environment. The main problem which prevents complete automation of mine is inability of equipment to estimate its position w.r.t. surrounding. Therefore in order to maintain safe working environment it is necessary to implement robots in underground mines. This paper will provide an overview of areas of application of robotics in underground mines.

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2. Application of robots in mining

Mining robots are capable of performing task like explosive placements, mine roof stabilization after blasting or extracting ores from inaccessible areas without full human operator attention [4].

Some examples of trends of automation in mining industry are as follows:

1. A robotic system developed for the purpose of stabilization or mine roof after blasting by drilling and bolting mine roof.
2. A robotic system developed for the purpose of induced controlled caving in case of massive strata or uncavable roof by performing drilling and blasting activity.
3. Automatic underground mechanical or electric haulage vehicles for transportation of ores.
4. Roadways development robotic systems.
5. Mine environment monitoring and firefighting robots.

3. Needs for robotic system in underground mines

3.1 Underground transport

In all underground metalliferous mines, material or ore is moved from point of extraction to the surface for further

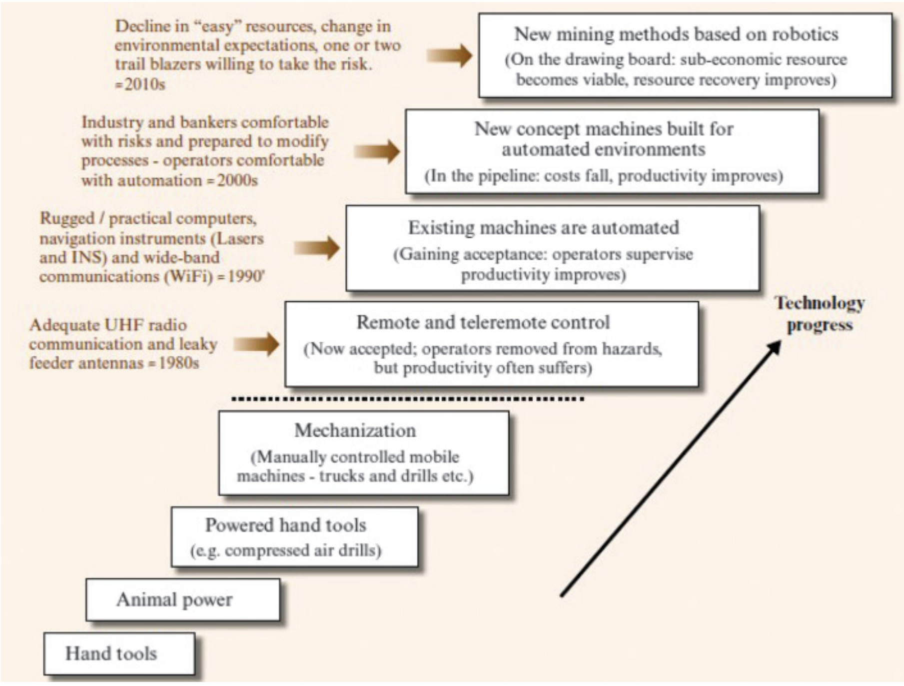

Fig.1 Evolution of mining technology (After Corke P et.al. 2008)

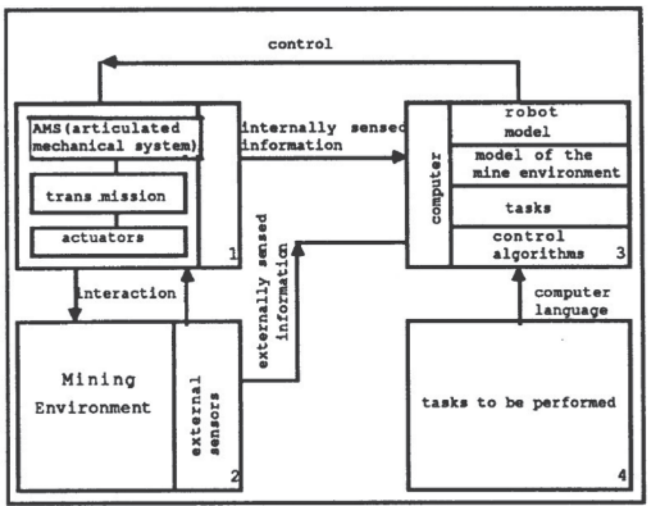

Fig.2 Schematic representation of mining robot function (After 1988 Janakiraman C R et.al.)

processing using existing conventional mining technologies like conveyors, haulage vehicles and skips. All the above mentioned technologies for transportation of ore can be automated using the knowledge acquired from automation technology used by manufacturing and processing industries.

Underground mine hauling trucks are used to carry the ore along the roadways to surface or atleast to the nearest loading point. Usually they are diesel powered and travel at speed of 6-10 km/hr and 20 km/hr at ascent in fully loaded conditions and at descend respectively. In some cases application of electric haul trucks is also seen but there application is very rare and uses pantograph to draw power from overhead electric power line and usually they are faster than diesel haul trucks ascending and descending at speed of 18 km/hr and 24 km/hr respectively [5].

Main reasons for implementation of the automatic haulage vehicles are to improve efficiency and safety by reducing labour cost, increasing operating duty, reducing wear and maintenance cost. Conventional load haul dumpers (LHD) is manually operated for tramming cycles but uses line of sight based remote control while they operate in hazardous area. This method is time consuming and hazardous since the process involves repetitively changing operating modes which has led to many accidents in which operators is being crushed by LHD during its return phase from stope. So, in order to avoid the risk associated with line of sight remote control many mines have introduced tele-operation for complete tramming cycles [6, 7]. But, resulted into slower tramming cycle times in comparison onboard operator based system which is due to the reduced perception and lack of feedback that naturally occur when the operator is no longer on vehicle. Therefore, in order to facilitate higher tramming cycles, productivity and reduced hazard to miners, onboard guidance and navigation system is necessary[5].

Many researchers are investigating the use of automatic LHD since past two decades. Earlier guidance and navigation

Fig.3 A load haul dump (LHD) vehicle (After Corke P et.al. 2008)

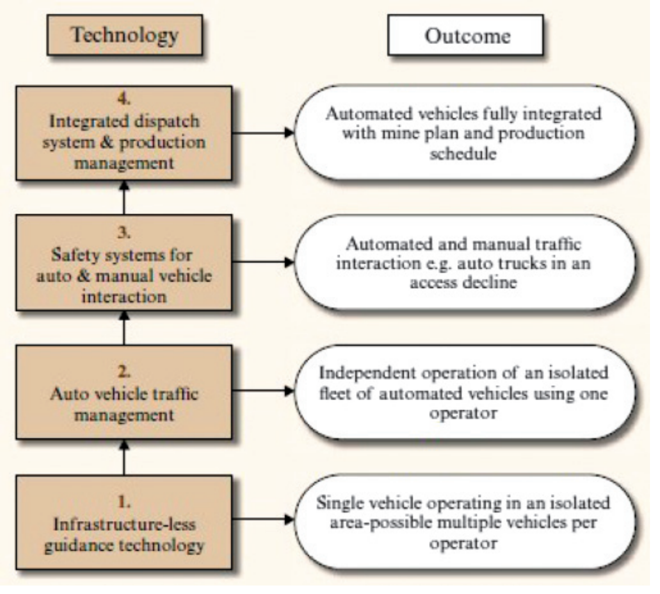

Fig.4 Evolution of automated mining vehicle technology and there outcomes (After Corke P et.al. 2008)

systems of automatic LHD used network of buried wires in concrete roadways [8]. Usage of concrete roadways is not common and is a limited solution. Another improved guidance system which was developed by researchers in earlier phase of development of auto-LHD involved installation of optical markers usually made of painted white lines [9] or retro-reflective tapes along the center line of roof [10,11] which will be tracked by upward facing camera installed on top of auto-LHD to estimate the offset of vehicles.

However there exists an another issue about skipping of corners along roadways by automatic LHD using above mentioned technologies due to non-availability of data along the track as a result of which the speed of automatic LHD must remain as low as possible to avoid skipping of any corner [5]. In order to resolve such problem additional means of measuring alongside the track position of LHD is required using odometry and RFID tags to correct the drift of the odometry. In late 1990s due to availability 2D LASER scanner new LHD guidance system were developed which requires installation of reflective markers along mine wall at predetermined intervals [12]. Thereby, eliminating the shortcomings of earlier guidance and navigation system of automatic LHDs.

3.2 Drilling

Semi-automatic drilling machine is used for development of roadways or extraction or ore from stopes. These machines are designed to drill holes autonomously with very little human supervisor. Though there are a large number of challenges regarding controlling the drilling operation due to the large onboard mass of drill bits and long telescoping arm attached to the mobile base with some degree of flexibility provided by hydraulic actuators and mobile base. Current technology involves manual placements of the drill bits and set up which rises the need for development in field of autonomous mobility and positioning [5].

3.3 Explosive placements

Since blasting is most hazardous operation which usually involves miners assembling detonators, primers and explosives then manually placing them into the blastholes. This process is extremely hazardous and has resulted into death of many miners in past decades not because of handling of explosives, rather due to confined nature of operation and closeness of miners to hydraulic/pneumatic equipment's and mine wall. So, there exists a prospect of application of robotics for the purpose of loading of drilled blastholes with explosives, detonator and primers [13].

Main problem associated with this task will be positioning of drilled holes, assembling the primer and detonators and insertion of hose into the blasthole. Sensors mounted non-rigid manipulators of long telescopic robotic can be used to locate the blastholes and can provide control guidance for explosive charging tube into the blastholes [5].

3.4 Secondary rock breakage

The process of secondary rock breakage is only implemented if in case the size of blasted/fragmented rock is too large to be transported by LHD to the surface or fed to the rock crushers. Blasting hole spacing, length and quantity of explosives are one of the major factors governing the size of fragmented rock. Usually small amount of explosives are used to further reduce the fragmented rock size like pop shooting, plaster blasting etc. But main problem arises when fragmented rock blocks the flow of ore at draw point of the metalliferous mines and application of secondary blasting in such case is dangerous and is one of area where researcher should apply robotics [5].

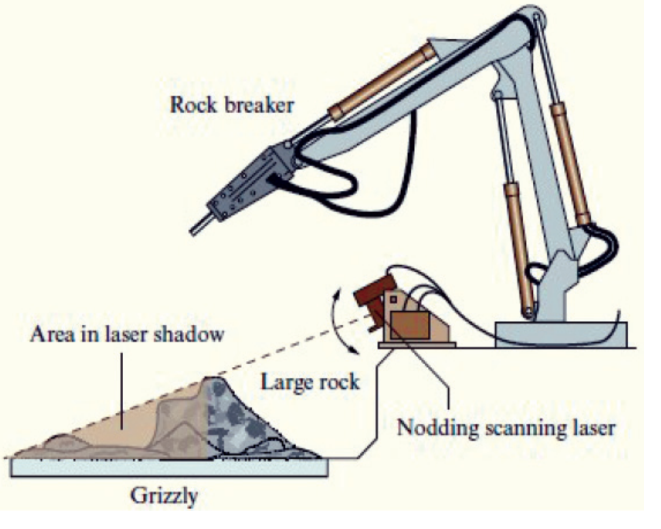

Fig.5 Mechanical rock breaker for secondary rock breakage (Courtesy: Corke P et.al. 2008)

Usually smaller boulders are lifted by LHD but large boulders are first crushed to suitable size before being transported to surface. The loading chute/hopper of rock crusher is fitted with steel grill or mesh called grizzly. Mesh size of grizzly is made such a way that only those rock which are small enough to crushed by rock crusher may pass through it. Therefore, large sized boulders are first needed to be crushed by secondary rock breaking process before it is passed through grizzly. This task is carried out by mechanical rock breaker consisting of hydraulic or pneumatic jack hammer with tools mounted on multi-jointed arm operated either autonomously or human being as when required. The main area of research would be detection of large sized boulders in muck pile and determining the location tool must be placed to break the rock [14].

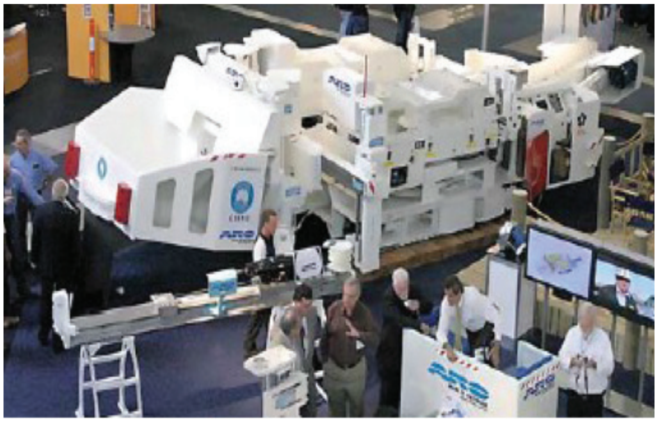

Fig.6 Prototype machine for roof and rib bolting (After Corke P et.al. 2008)

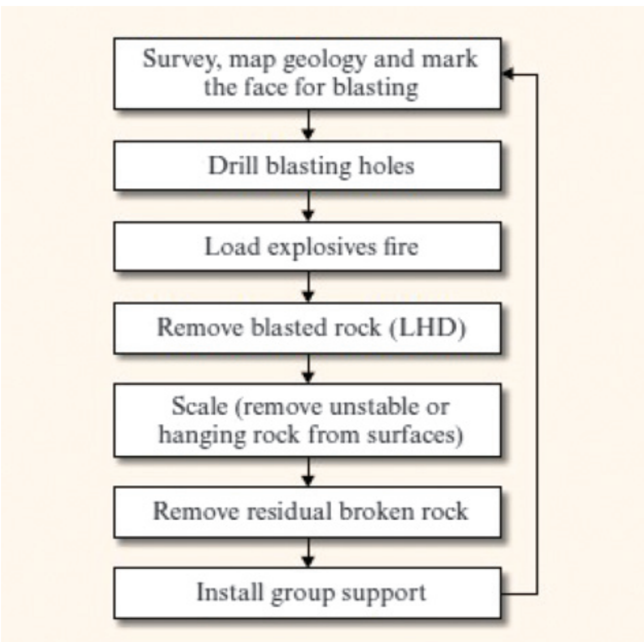

Fig.7 Sequence of operations for tunneling in metalliferous mines (After Corke P et.al. 2008)

3.5 Roadways development

In order to gain access to the ore/fossil fuels buried underground the very first need is to develop tunnels or roadways to access the ore. Depending upon function and location in metalliferous mines they are named as declines, inclines, drifts, crosscuts etc. [5].

Steps involved in conventional method of roadway development are depicted in Fig.7. These act as a process flowchart that is to be followed by roadway developing robots. The entire process can be briefly explained involving initial geological survey of area then drilling of blastholes along the direction of advancement of roadways. After completion of blasting operation blasted rock fragments are removed from the site by LHD in order to provide access for scaling operation to remove loose rocks from freshly blasted surface which is either done by hand or by using jumbo drills. Since scaling is potentially hazardous process these could be one of the potential area of applicable of robotics [5]. But process does not end here, again based on strength of roof rock and RMR we need to install the support system like roof/side bolting, steel mesh or shotcreting which itself is complex task involving drilling of holes, placements of epoxy resin cartridges, insertion of steel rock bolt and in some cases pretensioning is required to improvise the ground support system.

Main limiting factor in the speed of development of roadways, complex and lengthy procedure of installation of rock bolts which has caught the attention of automation industry to eliminate the challenges associated with conventional rock bolting procedure like automatically relocating drilled hole to insert roof monitoring devices e.g. tell-tale, borehole extensometer at regular interval or to insert epoxy resin cartridges and steel bolts and pre-tensioning it. Either a robotic system must be developed to carry out the above mentioned sequence of operation automatically immediately after blasting to improve the speed of advancement or the process should be partly automated to prevent miners from exposure to hazardous conditions [15].

3.6 Underground mine mapping and navigation

It is one of the important areas of application of robotics in the field of abandoned mine mapping involving usage of 2D Laser scanner. Fig.8 shows two different kind of robotic system developed for this purpose. The first image shows a cart equipped with four 2D laser finders which provides about mine cross section ahead of vehicle and structure of ground and ceiling. Second figure shows groundhog robot which is a tele-operated devices constructed from chassis of two all-terrain vehicles (ATVs) [16,17]. It consists of two 2D laser range finders, one pointed forward for 2D mapping and one pointed towards the ceiling for 3D mapping. Groundhog [18], a 1600 pound four wheeled all-terrain vehicle sized mine mapping robot fitted with laser range finder developed by graduate students in Cranegie Mellon’s mobile robot

Fig.8 Mine mapping cart with four laser range finders, pushed manually through a mine. Groundhog robot used for breaching difficult mine environment (Courtesy: Nanda S K et.al. 2010)

development class, made a successful trial runs in abandoned coal mines near Burgettstown which has been inundated since 1920 and created an accurate map of mine till 100 feet of mine roadways.

3.7 Mine environment monitoring

Mine environment is continuously changing process and is needed to be monitored specially in case of abandoned/ sealed off section of mines. Coal is susceptible to spontaneous heating and eventually results into mine fire which however requires source of leakage of oxygen into sealed-off area. So, regular monitoring of environment of sealed-off area is required to estimate the status of mine/auto-oxidation of coal to avoid extensive or blazing stage of mine fire. A robotic system must be developed containing gas samples collection system fitted with sensors which are capable of sensing carbon monoxide, carbon dioxide, methane and other hydrocarbon gases which helps in calculating fire indices to estimate the status to fire in sealed-off area. The data is continuously sent to the monitoring station located in surface which generates warning when alarming level is reached.

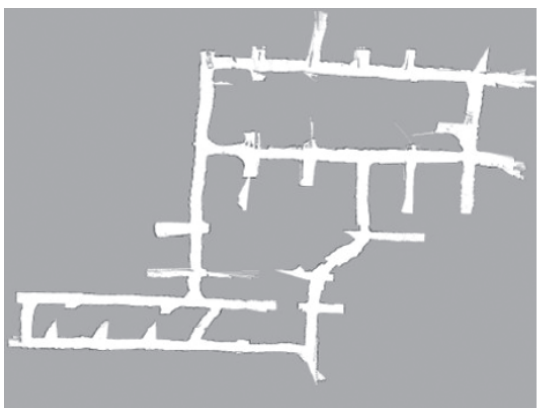

Fig.9 2D Mine map generated by LASER range which is scanned (Courtesy: Nanda S K et.al. 2010)

3.8 Mine fire fighting

A robotic system fitted with thermal imaging techniques or thermal sensors and firefighting system which continuously performs survey in mines to detect the temperature higher than expected or based on alarm issued by mine environment monitoring station the robot will travel to that point to control the fire by spraying fire retardant on mine wall or loose coal and inertize the mine environment of sealed-off area using CO_2 or N_2.

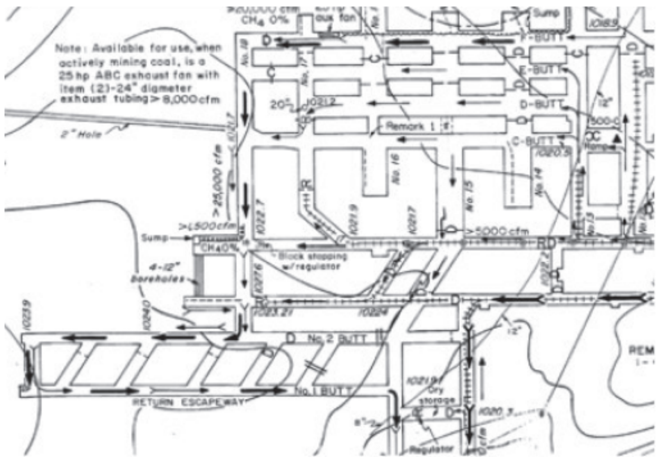

Fig.10: Rough hand drawn map of abandoned mine segment (Courtesy: Nanda S K et.al. 2010)

4. Conclusion

Currently mining industry remains hardest and hazardous work with large scope of application in various activities of mines and the main reason for implementation of robotic is the need for better productivity and improved safety of mining personnel. Mining robots are completely different than that of industrial robots which perform simple and repetitive jobs. Mining is continuously changing and complex process because of which robotics are not readily accepted by mining industry today. However, very less amount of work is carried out in mining robotics field and it has large scope of development keeping in view need to improvise the productivity and safety of personnel in mining industry by adopting more automation and robotics.

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PREDICTION OF SUBSIDENCE FOR THE CHROMITE MINE USING NUMERICAL MODELLING TECHNIQUES

(Continued from page 531)

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