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Mine Rescue Robot System – A Review

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Abstract

Underground mining is beset with numerous problems such as ground movement (fall of roof/sides), inundation, air blast, etc.; apart from gas explosions and dust explosions that are restricted to coal mines. Whatever may be the cause and type of accident or the extent of damage caused, it is a horrendous task for the rescue team to reach the trapped miners. The accident/ irrespirable zone contains increased levels of harmful gases like carbon dioxide and carbon monoxide and explosive gases like methane apart from a deficiency of Oxygen. The entire gallery or roadway is filled with dust and smoke, or water in case of inundation, hindering the visibility of rescue personnel. Thus, it is not an ideal situation for the rescue team to perform the operations. The first few hours after the disaster are the critical moments that could be the difference between life and death of the trapped miners. Hence, the ideal solution in such cases would be to deploy a wireless robot equipped with various gas sensors and cameras to aid visibility even in extremely low light conditions. This paper reviews some notable examples from the past and highlights important requirements for rescue robots along with some limitations encountered in the design of such robots.

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Keywords: Autonomous; Firedamp; Robot; Sensors; Wireless.

1. Introduction

Underground mines are broadly classified into two types: coal mines and non-coal mines. Non-coal mines basically consist of metalliferous mines that are relatively deep seated compared to coal mines. Underground metalliferous mines differ from the coal mines in the fact that there are no poisonous gas emissions in metalliferous mines. Underground coal mines are beset with the presence of toxic gases such as Carbon Monoxide, Carbon Dioxide, Firedamp (Methane-air mixture in coal mines), Hydrogen Sulphide, Oxides of Nitrogen, etc. Also, the coal measure rocks are not as strong as the host rocks surrounding the ore bodies in a metalliferous deposit, thus making it more susceptible to roof-falls and

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hence making strata control difficult. It is due to the above-mentioned factors, to a great extent, and a few of other factors, to some extent, that coalmines are considered to be more dangerous in nature.

Added to the above reasons is the problem of spontaneous combustion, which is more common in Indian coalmines. This is the case especially with the Jharia Coal fields, where millions of ton of coal is burnt underground. Spontaneous combustion, if not detected in the early stages, could be very fatal both in terms of material loss as well as loss of life.

The major problems encountered while working underground are confined space, high heat and humidity, unpleasant atmosphere and most importantly poor lighting conditions. These conditions are worsened immediately after an accident thereby making it difficult for rescue personnel to enter the accident zones and carry out the rescue operations on time. Owing to the high concentration of dust and smoke that fills up the atmosphere immediately after an accident, it is nearly impossible for the rescue team to proceed forward as they are virtually blinded with the thick cloud of dust. Therefore until the smoke and dust settles down, the rescue operations come to a standstill, where the first few critical hours are lost. In case of coal mines, noxious gases are present in the atmosphere and also, there are chances of second explosions due to coal-dust or firedamp, thus rendering the situation even more dangerous.

It is in such situations that the contribution of mobile subterranean robot becomes invaluable. Irrespective of the atmosphere, the robot can be put into action immediately after an accident and comes handy during surveillance of panels sealed in coal mines on account of spontaneous combustion. The application of robots have saved over 800 lives all over the world in various sectors and when such technology is adopted in underground mines, the number can rise manifold. The robot could also be used for 3-D mapping of the mine and collecting valuable data from inaccessible locations. This paper describes some recent works in the field of mine rescue robots, the on-going research in the field along with highlighting the requirements of rescue robots and the problems faced by them.

2. Rescue robots for underground mines

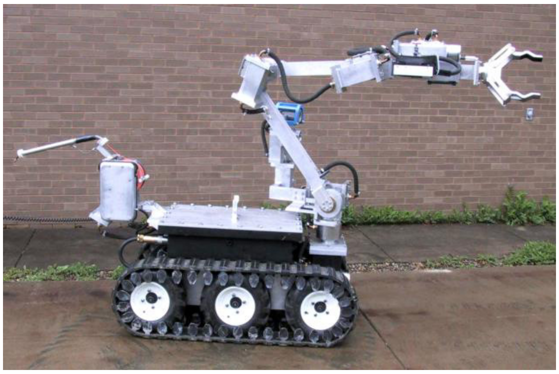
According to Robin R. Murphy, 2001, rescue robots can be classified into four major types as follows:

- *Unmanned Ground Vehicles (UGVs)*- UGVs work on the ground surface and can assist rescuers find and interact with trapped victims, in areas were it is dangerous or difficult for rescue personnel to enter.
- *Unmanned Surface Vehicles (USVs)*- USVs float on the surface of water, and can help rescuers to locate and bring the right equipment to the victims.
- *Unmanned Underwater Vehicles (UUVs)*- UUVs have the ability to search through water and identify fatalities, hazardous subject or material.
- *Unmanned Aerial Vehicles (UAVs)*- UAVs work without any contact with ground surface and can help in transporting medical aids to victims and to present a rough scenario of the accident site to the rescue team.

An efficient robot for underground rescue operations should be a combination of all the above four types to tackle with different situations existing in a disaster prone mine. However, this paper only deals with the UGVs. Some of the notable examples from the past are described below.

2.1. Wolverine V2

The Mine Health and Safety Administration (MHSA), USA, acquired the Wolverine robot (Figure.1) in 2001 from Remotec (B. Bharathi, 2013). It was a military robot, which used to serve as a traditional bomb squad robot and has been made mine permissible. It consists of a gas sensor input for continuous sampling and three cameras with remote display for the operator and is remotely operated by a fibre optic tether. It is designed to be operated from a safe place with a range of 5000 ft and transmit valuable data along with a live video feed. The robot is 1.27 m tall, 0.76 m wide and weighs approximately 550kg. Total cost was approximated to be $2,80,000. It was not easily deployable owing to its heavy weight and the use of a fibre cable for communications. It has been deployed in a few mine disasters although it did not the serve the purpose it was designed for.



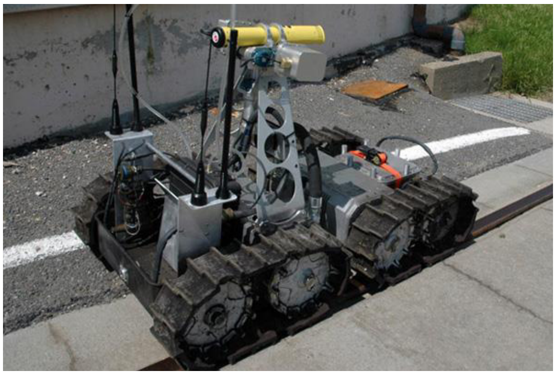


Fig. 1.Wolverine V2. Fig. 2. Gemini Scout

2.2. Gemini scout

Sandia Laboratories developed the Gemini scout (Figure.2) for the National Institute for Occupational Safety and Health (NIOSH) (Raghuram et al, 2012). It is a coal mine specific development that is 0.6 m tall and 1.2 m long. The Gemini-Scout is equipped with gas sensors, a thermal camera to locate survivors and another higher mounted pan-and-tilt camera to spot obstacles and the continuous gas monitoring information is wirelessly fed back to the operator along with colour imagery, and stereo camera depth information. It is lightweight enough to crawl over boulders and rubble piles and strong enough to withstand the pressures found underground.

It is intrinsically safe, and thus allowed to operate in hazardous mine environments (R. P. Chatterjee et al, 2009). The articulated body and rubber tracks enable it to tackle very rough terrain. The robot is guided by remote control and to make the control system as intuitive and easy to learn as possible, the engineers used an Xbox 360 game controller. Three units were manufactured and it has never been operationally deployed.

2.3. Numbat

The Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia, developed the Numbat (Figure. 3) in the late 1990's for use in coal mine emergency operations. Numbat is a remotely controlled vehicle used to convey information on the condition of underground mines in situations where it is too hazardous for manual exploration for enhanced situational awareness for rescue team assistance. Numbat is controlled with the aid of video cameras, joystick and GUI based control panel located in the control room. Four video cameras are mounted on the robot to assist in navigation. As shown in Figure.3, it is an eight-wheeled robot with a base length of 2.5 m and width of 1.65 m. It is still used in mining research project at CSIRO, and has never been operationally deployed in a rescue.

2.4. Ground hog

Carnegie Mellon University (CMU) developed the Ground Hog (Figure.4) for autonomous exploration and mapping of abandoned underground mines (T S Kumar Reddy et al, 2014). Over the course of its existence, Groundhog has traversed kilometres of abandoned coal mines and performed nine autonomous missions. It has produced high fidelity mine maps and models by logging extensive range data and video.

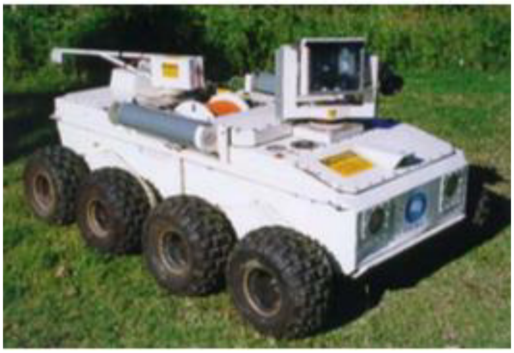


Fig. 3. CSIRO Numbat Fig. 4. Ground Hog

2.5. Sub-terranean robot

The Sub-terranean Robot (SR) is a compact, lightweight, caterpillar type tracked amphibian mobile robot with inter-changeability option for wheel type configuration (Figure.5). The Sub-terranean Robot is made up of a watertight compartment enclosing various equipment like on-board battery bank, camera and necessary electronics. Differential drive mechanism is employed using two separate motors along with two propellers. The robot is 0.55m long, 0.25m wide and weighs about 42 kgs. The robot is also equipped with SONAR for obstacle detection and underwater camera. The communication in SR is through radio frequency modules.

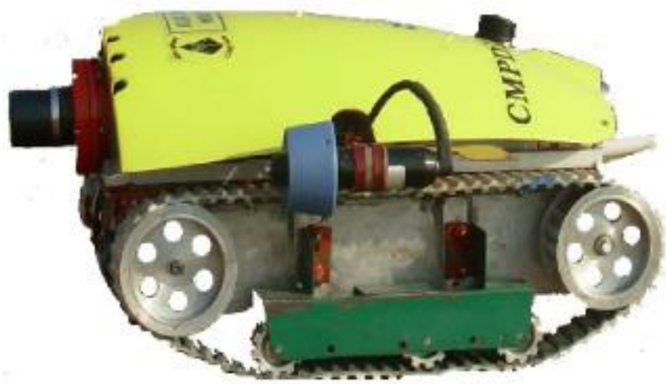


Fig. 5. Sub-Terranean robot

3. Functional requirements of mine rescue robots

Rescue robots have structures similar to that of military robots and use the same technology for searching, navigation and control, but only differ in the sense that rescue robots have more human-robot interaction for inhabitant response. In order to accomplish the post disaster surveillance without any difficulties in the harsh environments, it is very much crucial for the mine rescue equipment to function reliably. The first and foremost design requirement of any rescue robot to be deployed in underground coal mines is that it has to be intrinsically safe and flame proof. Some of the important functions of a rescue equipment are regarded as Searching, inspection and mapping, dirt removal, structural inspection and the other essential functions being medical assistance and evacuation of casualties, acting as a mobile repeater, providing logistic support and serving as a substitute for a team member (Bruno Siciliano et al, 2008).

a. *Searching*: The most crucial requirement of a rescue robot is to handle search operations in the dark and formless mine environment to detect possible hazards or to search for fatalities in the hazardous accident-prone environments with a great degree of precision and control. It is essential that these search operations be carried out quickly without increasing the risk for the rescuers or victims.

b. *Inspection and mapping*: The robots are required to provide the human rescue team with general information about the situation and create a reference of the destroyed surroundings, covering a wide area in as little time as possible.

c. *Structural inspection*: The sensors must enable the robot find an optimal path into a debris structure in order to fasten up the rescue operations and at the same time make it safer. On-board lighting and live video transmission helps the rescue personnel assess the situation and hence they could be well prepared for the operations. Thermal cameras could be really handy as they make victim identification easier as well as assist in detecting fires and other leaking gases.

The other requirements of rescue robots include the ability to move debris which otherwise would act as hindrance to the rescue operations. The robot should also be equipped with various gas and temperature sensors to enable continuous monitoring of the surrounding environment to assist the rescue personnel make faster and better decisions. All the sensors and cameras need to be rugged, dust proof and waterproof and should be of industrial grade quality to perform reliably in the hazardous environments.

4. Limitations for use of rescue robots in underground mines

The prime reasons behind the limited application of robots in underground mines are the unstructured nature and the constant state of evolution of the mine, which requires the robots to be highly flexible and adaptive. Most of the existing robots are heavy and hence are not ideally suited for easy transportation and deployment during the rescue operations. Many of the existing robots are unable to establish a reliable communication to the base station and hence are not really efficient in accomplishing their tasks. Tethered communications provide good feed, but the length of the cable limits the range and the cable is susceptible to tangling, breakage, and being run over by the robot. Wireless communications have not proved to be reliable in underground mines the robot has to maintain Line-Of-Sight with the base station, which is seldom possible in underground mines.

Other limiting factors of the robot include the presence of standing or flowing water and difficulty in maneuvering around mining equipment or tracks and low roof heights with protruding roof supports, plumbing, and wiring. Since the robots run on battery power, the type and capacity of the battery are also major limiting factor in the deployment of such equipment.

5. Conclusions

Rescue robots play a crucial role in the post disaster rescue operations. A rescue robot helps find the location of accident, search for survivors to assist in first aid treatment and informs the rescue team about environmental conditions and the possibility of survivors at the disaster prone area. Several rescue robots are under development and some have already been deployed in some emergence situations, though they have not performed to the expectations. The challenge faced by the industry is to develop rescue robots that are more advanced, intelligent and boasts robust and reliable hardware to work in critical zone in such a way that it can handle all possible obstacles (J.Baca et al, 2010). Swarm robots or multi-robot teams that work together in a team with a high communication and synchronization between them are capable of extending the communication and sensor network. But this concept is still in the early stages of development and may not be seen in the mining industry anywhere in the near future.

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