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Application of Wireless Visual Sensor for Semi-Autonomous Mine Navigation System

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***Abstract*—**The present paper represent the efforts undertaken for the development of an semi-automatic robot that may be used for various post-disaster rescue operation planning and their subsequent execution using one-way communication of video and data from the robot to the controller and controller to the robot respectively. Wireless communication has been used for the purpose so that the robot may access the unapproachable places easily without any difficulties. It is expected that the information obtained from the robot would be of definite help to the rescue team for better planning and execution of their operations.

***Keywords*—**Mine environment, mine navigation, mine rescue robot, video data transmission.

I. Introduction

EXTRACTION in underground space for exploitation of the existing mineral resources, involves working against the nature in an odd environment. For both the two distinct cases like the underground and open cast mining industry, keeping track of proper and exact details of the mine workings is very vital towards minimizing the chances of accidents and there by increasing the productivity of the mining operation. Thus navigation and regular monitoring based on semi-autonomous robots for accessing such accident prone areas of the mine workings proves to be a better alternative. It has been observed that most of the accidents occur mainly due to improper monitoring and maintenance facilities available and / or provided to the mine workers.

An effort has been made in this investigation to come up with an unmanned operation for execution of the above mentioned tasks mainly with the help of the visual information available from the underground robot to the control station placed within the access range. The proposed visual and data communication is based on the wireless mode of transfer. The present setup makes this available using the one-way communication mode.

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A simplistic approach has been assumed for the testing of the performance of the semi-autonomous robot. It has been seen that this performs well under the simple assumptions of the conditions prevailing at the underground mining excavation sites. The recent fatality statistics for both underground as well as opencast mining operations worldwide indicate that the most serious risks to the personnel are from different mining conditions especially that from the inaccessible areas of the mines where regular systematic monitoring and maintenance operations are difficult and hence, none of these operations are not carried out on a systematic basis. It is true that there is no control of the human operators on such unwanted happenings.

Since proper mapping of each and every mining operations need a special attention in order to reduce the chances of any kind of accidents, an effort has been initiated to carry out this task without human intervention using the latest developments in the field of robotics, aided with the domain specific information. The related information would also be tried to be collected and analysed for judging the status of the level of hazard prevailing at any given point of time. This operation is expected to help the mine authorities to remain prepared with all the possible rescue measures.

Furthermore, the lack of knowledge regarding the geological integrity and environmental condition of the mine also hinder rescue and recovery efforts. Robotic technology offers significant potential to improve the plight of the rescue workers by reducing exposures to hazardous conditions. A robotic vehicle can explore the mine and provide valuable information to the teams to assist in planning and implementing search and rescue operations.

The present robot is made up of mechanical module, electronic module and control module. The mechanical module is designed to facilitate the movement of the robot over the rough mine roadways. The electronic module is designed to take into consideration the video, data transmission using the wireless mode of communication with the help of the ATMega32 micro-controller. And, the control module is designed to interact with the robot from the control room during its navigation of the different hazardous zones in a mine. The application area for the presently developed robot is a very simple mining situation where the effects of hazardous gases and other noxious gases have been ignored [15]. This study thus forms the basis of any further extension of our present work to real life mining scenario where the risk to human life needs to be minimized and at the same time the

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information regarding the existing mining environment needs to be obtained for better planning of the rescue operations.

At present the robot has been found to satisfactorily navigate through the simulated mining conditions in the departmental space, with one-way video and data wireless transmission system. In future this needs to be modified to handle the two-way wireless data transmission, with very high video data volume. An addition of programmable camera having the facilities of zooming and adjusting to the field of view, in the future may improve the utility of such semi-autonomous robots to the mineral industry.

II. Literature Review

The papers [1, 2] describe the different navigation techniques developed by the robotics research community over the last decade that may be applied to a class of underground mining vehicles (LHDs and haul trucks). The current state-of-the-art in this area has been reviewed and it is concluded that there are essentially two basic methods of navigation applicable. An implementation has been described for a reactive navigation system on a 30 tonne LHD which has achieved full-speed operation at a production mine [6].

There have been reports of study on the image mining for robotic vision based on concept analysis, where the process of image mining for robotic vision and the use of concept analysis technique have been mentioned as an important technique. The paper proposes a novel framework of image mining for robot-vision based on the concept of lattice theory and the cloud model theory. Concept of lattice reflects the process of human’s concept formation with the mathematical background of formal language. Cloud model is a transformation model between qualitative concepts and quantitative numerical values. Image mining for robot-vision is considered as a process of concept extraction from different granularities (image pixels, image pixel groups, image features, image objects, image files and image databases). The methods of image mining from image features (texture features, color features, shape features, spatial relationship features) are introduced in the paper which includes the basic steps like: pre-processing of the images, use of cloud model to extract concepts, use of concept lattice to extract a series of image knowledge (association rules, clustering rules and classification rules) [14]. At last, a software prototype is designed and developed, and some experiments confirm the validity of the proposed framework.

Two robotic systems [3] for acquiring high-resolution volumetric maps of underground mines have been described. The systems have been deployed in an operational coal mine in Bruceton, Pennsylvania, where they have been used to generate interactive 3-D maps. The approach includes a novel sensor head, assembled from multiple SICK laser range finders, and a real-time algorithm for scan matching that generates accurate volumetric maps. The scan matching algorithm performs horizontal and vertical simultaneous localization and mapping (SLAM) [7, 11]. The data from the horizontal scans is used to remove artifacts in the vertical scans, and vice versa. The system can construct full 3-D volumetric maps hundreds of meters in diameter, even when no odometry information is available.

Study has also reported of the use of robotics from space to underwater mining [4]. The exploration of mineral resources on the ocean floor calls for unmanned systems and machines controlled from the surface. Removing operators from the vicinity of worksites introduces many technical challenges, like: low situational awareness in unknown environments, complexity of the operated machines, and the need for high bandwidth real-time communication systems etc. Precise maps of the worksites underwater do not exist and accurate localization of remote machines at the end of several kilometer long tethers is not straightforward. Additionally, the cost of teleoperation is high - it requires highly skilled operators as the cost of an error is extremely high [8, 9, 10, 12]. These factors make it difficult to exploit the underwater resources economically and with minimum environmental damage.

Challenges of operating underwater mining machinery are similar to those of robotic systems on-orbit or during planetary exploration. For space systems a combination of the two approaches is used to address the difficulty of tele-operations, like: a) presenting virtual models of worksites and controlled hardware to operators and b) increasing the remote systems’ autonomy. Immersing the operators in virtual environments increases their situational awareness [5]. Autonomy enables the remote systems to perform some of their tasks using on-board sensors and intelligence, control certain degrees of freedom and to operate safely with minimum operator involvement. Planning space missions and developing necessary technologies includes various structured processes, e.g., phased development, assessment of maturity and difficulty of required technologies, and analysis and management of project risks. Technologies and expertise gained in developing systems for space may be useful for autonomous seabed mining systems [13, 14].

There are reports of autonomous exploration and mapping of abandoned mines that mentions about experiments with a robotic system designed to autonomously explore and acquire three-dimensional (3-D) maps of abandoned mines. This would be really useful for topological exploration of abandoned mines.

III. Statement of the Problem

In order to gain understanding of the requirements of the developed robotic rescue vehicle, it is useful to summarise the role of this vehicle. Its primary purpose is to provide the rescue team with immediate information of the mining conditions after any emergency incident. Sending this vehicle to the affected site before the rescue team not only minimizes the risk to the skilled personnel, but also provides an invaluable source of timely information regarding the mine’s environmental condition that may aid the rescue team in better

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planning of their operations.

When the mine accidents occur, there is a better comfort situation produced, if the following information are made available by some means, like location(s) of the trapped miners, establishing a two-way communication with the miners and information regarding the environmental conditions (for example the temperature, carbon monoxide level, presence of methane, or other hazardous gases etc) along with the access path information to the trapped miners. Further, continuous and remote monitoring of the mines and the environmental factors along with a proper planning for geo-mapping of the excavations would provide better and more useful information to the surface personnel in planning the day-to-day activities while providing the best services to the affected individuals. Although, the present application has some limitations in the implementations made as of now.

IV. Proposed Solution

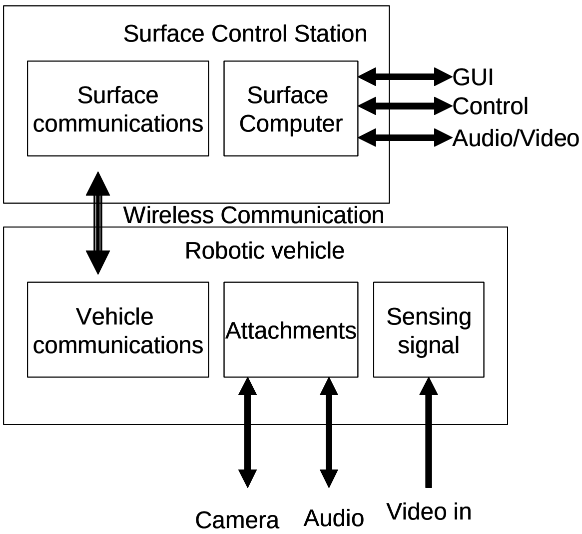

Fig. 1 The basic architecture of the rescue robot with wireless mode of communication established.

The authors propose as-of-now a single unit of wireless communication system to be implemented to address the above issue. A WSN typically uses IEEE 802.15.4 or ZigBee standards and frequency bands such as 2.4 GHz ISM (Industrial, Scientific and Medical) band. 900 MHz band, 433 MHz band, or 315 MHz band for communication. It could support data rate up to 1Mbps. A complete network of such units may be put in place for the execution of the mine-wide monitoring, once this becomes successfully tested on a trial basis. Fig. 1 shows a schematic of the present architecture for the rescue robot planned and designed. This is designed mainly for capturing the video signals from the hazardous places to the surface control station.

V. Platform

The present robot uses a custom made chassis with an embedded processor attached with a low light video system and the wireless transmitter units. It is operated using a suit of software bundles that handle everything for its navigation. Here we describe these in shorter details.

A. Chassis

The proposed rescue is a rugged platform specifically to traverse the rough and unpredictable terrain of mining environments. The common obstacles assumed are those caused due to various mine related accidents, and this is simulated to run over these simulated materials. The details about the chassis are provided in the Table I.

TABLE I
Mechanical Specifications of the Robot

Sl. No.	Specifications	Values / types
1	Weight	1.5 kg (depending on the battery)
2	Motor	Vex Continuous Rotating Motor
3	Length	40 cm
4	Width	26 cm
5	Height	21 to 28 cm, depending on tilt position

Although there are various commercial models available that are having clearances from the safety point of view to be used in adverse mining conditions, but for the present study, a miniature model was planned for its testing to operate under adverse conditions in the laboratory based conditions.

B. Perception

The sensor layout of the robot is depicted in Fig. 1. This serves as the basic information for capturing the visual information regarding the affected place as of now. The robot as of now also tries to capture the audio signals from the robot end and forward the same to the operators sitting at the control room. Capturing other useful data related to the mining environment, is also under process.

The two-way communication for both these types of signals is being tried out for the next update.

C. Communication

The installed communication system in the robot is a commercially available system which has been configured for this specific purpose, with a bandwidth and fragmentation threshold set to maximize the integrity of the system. The present system can handle one-way communication of the video signals from the robot to the server where they are analysed by the human operator visually for the environmental conditions. After some decision is made/ taken the same data is also transmitted through the wireless communication channel back to the robot for its execution.

D. Control

The robot in the present case has semi-automatic mode of movement, where the actions taken by the robot are guided by the surface operator based on the signal received from the sensing system through the communication channel provided for the purpose. Presently, only single nodes for the transmitter as well as the receivers are in use, but the actual layout of the real-life mines would be totally different and extensive where the use of multi-point access points would become necessary. This would also be tested before the actual field testing of this robot.

VI. Semi-Autonomous Navigation

The proposed robot uses the canonical sense, communicate, plan and act activities in sequence. These are explained below:

Sensing: From a static pose, the currently active sensor (depending on the direction of motion) takes videos of the mining environment for being sent to the operators to take the decision. The rate of the video is 30 frames per sec, and the resolution is 450x650. The range of the video varies from 200 to 250m. The adjusting and focusing capacities are also provided inbuilt to the camera at a given distance.

Communicate: The complete video is communicated using the wireless channel placed with the robot. This is mostly one-way, although there possibilities of making this both-way. The data as reply to these video signals received from the operator is also being sent through the same communication channel. Based on the collected videos, the path calculation would also be executed, this is being planned. To feed in more autonomy the robot would be free to take these decisions in combination to its own observations.

Plan: The part of planning needed for the execution of the other associated activities of proper generation of the image sequences now and of the 3D model in future time would also be made out of the video frames available from the camera. Thus the best path to reach out to the affected and trapped persons may be easily achieved.

Action: The proposed action and the movements to be taken by the robot which are decided by the surface operator are executed by the robot using the attached components at the robot. Once the goal has been reached the robot would stop and if instructed would repeat the same cycle after receiving the signal.

The sense, communicate, plan and act paradigm is a very well known and established model for the robotic systems in both outdoor and indoor environments. The processing time of the robot may be improved depending upon the capacity of the attached processor of the robot and this would definitely have its implications on the cycle time of the robot. Since, this is being planned for its probable use in adverse mining conditions, it would be best to use the same for its sensing the hazard area at a quicker time on the time scale so as to capture the scenario as quickly as possible and hence the dynamic features are obtained without sending any human operator.

This robot needs a lot of robust statistical testing and use of best algorithms for its better execution, before any field operations are tested and planned for the same.

VII. Some of the Results

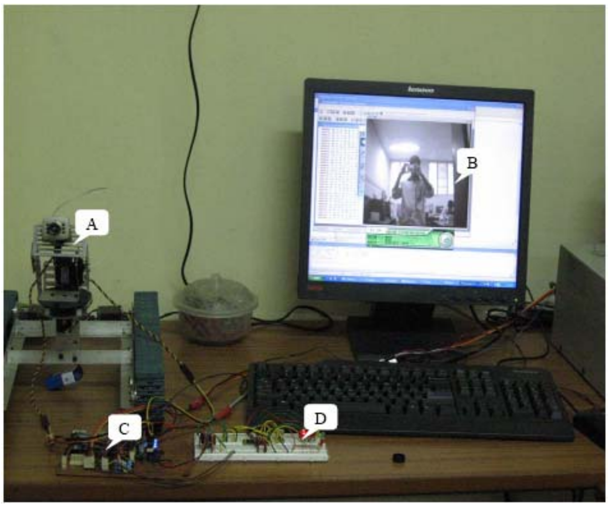

Fig. 2 The complete setup of the robot with the server at the control room that needs to work in tandem for the execution

Fig. 3 The robot in the testing mine gallery of the department

Fig. 4 The complete robot unit with the pan-and-tilt mechanism for better navigation

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The Figs. 2, 3 and 4 represent the different aspects of the semi-automatic robot that has been developed. Fig. 2 shows the robot along with the communication server that is needed for the execution and navigation of the robot. Fig. 3 shows the robot in the departmental gallery and Fig. 4 depicts the look of the presently developed robot.

VIII. Conclusion

The present work concentrates on building the prototype of a simple rescue robot designed to work under simple mining conditions, taking some assumptions help to simplify the first version of the design. In this research work main thrust is given to a rugged and robust mechanical design and to achieve the initial stage of wireless communication within a range of 100 m. Wireless communication includes audio, video and data transmission, we have established till now one-way communication and this would be updated to two-way communication in the next stage and we also would be making the audio communication work then. Selection of motors of high torque and optimum RPM is also one of the key achievements. Besides this panning and tilting of camera in synchronization with the motion of the robot has been taken care of and success has been achieved in smoothing the motion of the camera, thus decreasing the vibration effect on the frame. Robot has been successfully tested in the department.

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