2008 IEEE International Conference on
Robotics and Automation
Pasadena, CA, USA, May 19-23, 2008

Preliminary Report: Rescue Robot at Crandall Canyon, Utah, Mine Disaster

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Abstract—**This video provides a preliminary report of the use of a rescue robot from Aug. 24, to Sept. 2, 2007, at the Crandall Canyon, Utah, mine disaster. The customized Inuktun teleoperated robot was able to traverse over 1,400 feet through an 8 7/8" uncased borehole drilled, enter the mine and travel approximately 7 feet. The robot showed that the walls had deteriorated, indicating that a major collapse had occurred. The large debris combined with dense mud created unfavorable navigational conditions for the robot. The robot was lost on the ascent, approximately 52 feet from the surface, due to eroding borehole conditions. The video identifies open research questions.**

I. Introduction

THIS on August 6, 2007 six miners were trapped or killed in the collapse of the Crandall Canyon mine in Utah. The type of collapse in the mine prohibited the use of the MSHA mine permissible (explosion proof) robot, a variant of the Remotec Wolverine. Meanwhile, boreholes for air sampling were drilled into the areas where the miners were expected to be and the samples showed little or no methane. Small video camera "probes" were inserted in boreholes but could only see a short distance beyond the hole and could not see around corners. After three rescuers were killed and three others injured trying to enter the mine on August 17, the Mine Safety and Health Administration (MSHA) considered waving the mine permissibility requirement and actively considered deploying a robot through one of the boreholes. The Center for Robot-Assisted Search and Rescue (CRASAR) at the University of South Florida assisted MSHA with exploring other robotic options based on their prior field experiences, including deploying a small rescue robot for MSHA at the Newmont Midas Gold Mine disaster in June, 2007. On August 21, MSHA approved the acquisition and use of a small, non-mine permissible robot to enter the mine through boreholes.

This work was supported in part by the Mine Safety and Health Administration, NSF grants EIA-0443924 and CNS-0224401.

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On Aug. 24, 2007, a five person team from MSHA, CRASAR, Inuktun Services Ltd, and PipeEye International converged in Utah under the direction of Dr. Jeffrey Kravitz, MSHA Chief, Scientific Development, Technical Support. Inuktun Services, Ltd., provided a customized mine cavern crawler robot with 1,000 ft of tether. The 1,000 ft of tether was insufficient as the boreholes were on the order of 2,000 deep. PipeEye International, a pipe inspection company, provided a controller system, including a winch and 1 mile of tether. PipeEye personnel were also responsible for piloting the robot. The Center for Robot-Assisted Search and Rescue observed, collected performance and human-robot interaction data, and advised in the field.

II. Selection Criteria

Three criteria were used in selecting a robot for this mine rescue: *suitability for the environment, history of use in extreme environments,* and *immediate availability*.

Five qualities of the environment posed extreme challenges for the robot. First, the depth of the mine from the surface meant that a robot would have to transit through an approximately 2,000 ft drop before reaching the mine void, pass through the wire mesh ceiling supports and any trapped rubble, then drop 8 feet to the floor, and finally begin searching up to 1,000 feet beyond the opening. Second, the small diameter borehole and lack of a smooth metal casing sleeve was another problem. The borehole diameter was 8 7/8 inches but since the hole was uncased, it was irregular and could be less than 8 7/8". Requests were made for a 12" cased borehole, but the company felt these were not an optimal use of drilling time in the context of the larger rescue operation and thus continued to drill 8 7/8" boreholes. Third, groundwater, seepage, and drilling artefacts mandated a waterproof robot. Fourth, once on the mine floor, the robot had to have sufficient traction in mud and rubble in order to move to viewpoints beyond what could be seen by the video camera probes. The fifth challenge was the complete darkness and deconstructed nature of a disaster. As a result, a pan tilt zoom camera with as much lighting as possible was considered essential.

The second criterion was confidence in the platform. The platform had to exhibit some history of the use or direct proof of suitability. For example, reliable waterproofing and resistance to fine grit and sand is a demanding design and manufacturing problem; such hardening is generally out of the reach of a company that does not routinely make such devices make and test such devices.

The third criterion was immediate availability. Once the decision was made to permit the use of robots of non-mine permissible robots, the response was already entering its third week. While the possibility of finding a living survivor was extremely low, any information needed to be collected for the families before complete collapse of the mind prevented future efforts.

In retrospect, a fourth criterion should be added to the criteria for selection of a robot system for future responses: *the availability of experienced operators*. The Crandall Canyon mine rescue represented three distinct different mobility regimes: borehole, mine floor, and the transition between the two. The degree of novelty of the environment mandated human operators over an autonomous system. Since the mine represented new conditions for a robot, it was important to match the robot with operators who had significant experience with similar robots and experience operating those robots under the similar environmental conditions. A novel robot with an operator who did not have significant experience in similar field conditions would be unlikely to succeed.

III. Robot

The robot selected was a custom platform built by Inuktun based on their waterproof Versatrax system. Inuktun was able to dedicate resources to design, manufacture and ship a platform in three days, with an additional day on-site for integration with PipeEye's Long-Range system – a deep penetrating pipe inspection system with a mile of fiber-optic tether. The robot was built using twp Versatrax components mounted to a specially designed narrow chassis – a compromise between optimal maneuverability and fitting through the borehole. A hinged tether control arm at the back prevented the vehicle from running over the tether while backing up or during spot turns. Finally, a motorized raise mechanism was provided for the main Spectrum 90 camera which had to be stowed behind the vehicle during borehole transit; the control arm providing a convenient and protective saddle. When the vehicle was safely on the mine floor the camera could be raised to a vertical position for 360° panoramic viewing using its continuous pan feature. The platform was carried by a pair of brass Minitrac tractors, providing pulling power for 1000 feet of tether and each contributing 27lb of weight, giving the 70 lb vehicle a low and stable center of gravity. A second, fixed camera was located between the tracks toward the front for viewing the descent down the borehole and, if not covered in mud upon landing, was to aid in navigation on the mine floor. The final size of the robot was approximately 8" wide and 19½" long, with an additional 14½ inches for the tether control arm. Minimum clearance in the borehole was about 3/8".

IV. Runs

Four runs were conducted with the rescue robot, in only one did the robot enter the mine. PipeEye personnel piloted the robot due to their extensive experience with similar equipment. On Aug. 26, the robot entered Borehole Three. Part way down the lowering system failed, causing a jar that disconnected some electronics in the interface canister between the Long Range system and the robot's tether. The robot was removed, repaired, and then re-inserted on Aug. 27. The tether was at that time shortened to 330 feet to ease deployment difficulties, while still being long enough to be useful in the mine.

In the second deployment, the robot reached 1410 feet - 10 feet short from the exit- before encountering a narrowing of the borehole. After over 40 minutes of effort, the robot could not get past the blockage and the run was ended. On Aug. 30 the robot entered Borehole 4. It was lowered only a few hundred feet before it was removed in order to clean the lens from the buildup of debris and drilling foam. The robot was immediately reinserted, and this time was able to exit the borehole into the mine void and then onto the mine floor. At this time, the robot was able to move about 7 feet into the mine, sliding on a mound of drilling tailings under low hanging ceiling mesh. The search showed the walls had deteriorated and the floor was littered with chunks of coal at least two feet high and a risk to navigation. The decision was made to retrieve the robot, but it became trapped by the mesh and could not be freed. The team left the robot overnight under a fairly clear stream of groundwater in order to try to clear the Spectrum 90 camera. The team returned in the morning and was able to untangle the robot from the mesh and reenter the borehole. Recovery went smoothly until about 52 feet from the surface whereupon the interface canister encountered severe washout and large boulders, as the borehole was actively eroding. After two days of removal efforts the robot was lost when the fiber-optic tether to the interface canister finally broke.

V. Open research questions

The findings from the rescue are still being processed and footage not released to the media will become available after the mine disaster inspection has been completed. However, there are several lessons learned. Sensors, especially self cleaning sensors are need. Sensor placement remains an issue. Alternative forms of mobility should be investigated, particularly snakes. While the mine cavern crawler was a tethered robot, the problems with the mesh at Borehole 4 show that there are clear advantages to a wireless robot. However, a reliable wireless robot requires both reliable power and network communications. More attention should be paid to human-robot interaction, especially since operators are generally fatigued and the environment is deconstructed.

Acknowledgments

The authors thank Sam Stover for his assistance. Our condolences go to the families of the lost miners and we hope that the lessons captured in this video will assist with future responses.