SAND2017-13770C

Mine Rescue Robotics: Gemini-Scout – 18507 (DRAFT)

Jake Deuel, Jon Salton, Clint Hobart, Justin Garretson, and Diane Callow
Sandia National Laboratories

ABSTRACT

Gemini Scout is a mine rescue vehicle developed by Sandia National Laboratories to help locate and communicate with trapped miners following an accident. In a mining accident, first responders are working against a myriad of dangers to assess the situation and rescue trapped miners. The robot can enter potentially dangerous situations ahead of rescuers to evaluate hazardous environments and help them determine how operations should proceed. The Gemini Scout mitigates many of the potential dangers and allows exploration and assessment without further endangering individuals. The robotic vehicle can operate in hostile, debris strewn, dark, muddy, high temperature, and explosive environments. It has extreme ground mobility including operation in up to 18 inches of water and ability to traverse large rubble piles and cross railroad tracks. The vehicle provides gas and temperature sensing as well as pan, tilt, zoom color and thermal camera video streaming back to an operator in a safe zone. The extreme mobility of the vehicle and the modularity of the platform allowing easy integration of sensors are directly applicable to many needs within Waste Management. The development of Gemini Scout was funded by National Institute of Occupational Safety and Health (NIOSH) and the primary customer and certification entity was Mine Safety and Health Administration (MSHA). Lessons-learned during development and steps leading to certification are also applicable to the development of systems for unique Waste Management sites.

INTRODUCTION

In the first moments after a mining accident, first responders work against the clock to assess the situation and save the miners. But countless dangers lurk: poisonous gases, flooded tunnels, explosive vapors and unstable walls and roofs. Such potentially deadly conditions and unknown obstacles can slow rescue efforts to a frustrating pace. To speed rescue efforts, engineers at Sandia National Laboratories developed the Gemini-Scout Mine Rescue robot that would eliminate some of the unknowns of mine rescue operations and arm first responders with the most valuable tool: information.

In 2008, Sandia National Laboratories (SNL) developed the Gemini-Scout mine rescue platform through a National Institute for Occupational Safety and Health (NIOSH) sponsored program. The Gemini-Scout was created to assist in underground mine rescue missions. It was designed to go into potentially hazardous environments to assess the conditions (structural, air quality, temperature) and to enable two-way communications with potential survivors prior to human rescue teams being able to enter the area. Although NIOSH funded the project, the end user and certification entity was Mine Safety and Health Administration (MSHA). The intention of the original development program was to provide a means for NIOSH and MSHA to test and evaluate the use of an unmanned system for mine rescue purposes, and the development of the CONOPS (Concepts of Operations) for its use in such a situation. It was expected that the initial developed platform would provide a means for certification of later versions of the remotely operated vehicle.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

The initial proof of concept vehicle was successful as it allowed the users and sponsors to gain a better understanding of how a scout robot would be used in mine rescue applications and supported the discussion of required features and operational requirements. The mobility of the Gemini-Scout Mine Rescue robot was demonstrated in a wide variety of scenarios. Potential certification issues were identified and incremental design changes were implemented several years after the original project inception.

The Gemini-Scout platform is a dual tracked-chassis design, which gives the robot excellent mobility in unstructured environments. It can travel over significant rock and rubble piles and was designed to sink in up to 18 inches of water and travel along the bottom. The Gemini-Scout is teleoperated in a wireless mode except in extreme cases where a line of sight is not possible. In these cases, it is teleoperated using a ruggedized fiber optic cable to ensure continuous functionality of the vehicle and all its peripherals. In addition to the base mobility platform, the Gemini-Scout incorporates many other features to help it succeed in its mission. The electronics are mounted in explosion proof housings to ensure safe operations in hazardous gas environments. It has elevated pan/tilt cameras to aid in navigation even in standing water. A four-channel video link and two-way audio on the vehicle help to ensure located survivors can communicate with the robot operators. The platform also incorporates a MSHA-approved multi-gas sensor to monitor air quality. SNL believes that this technology is broad enough to be appealing to other first responders, such as police, firefighters and medical personnel. Gemini could easily be fitted to handle earthquake, fire, and radiological scenarios, and it could provide relief in currently inaccessible situations.

DESIGN

The Gemini vehicle is a highly mobile, Sandia-developed, teleoperated platform comprised of two tracked vehicles linked with a passive, 2 degree of freedom joint that enables far greater mobility than can be achieved with one single, monolithic vehicle (see Figure 1 and Figure 2). A traditional single body tracked vehicle is limited in the height of obstacles it can climb over. This limit is roughly dictated by the wheelbase of the track driving wheels. The Gemini vehicle, with its two identical tracked vehicle platforms joined by a passive joint can negotiate obstacles several times higher than the limits of an equivalent single body vehicle.

Figure 1. Photo of the Sandia-developed Gemini vehicle.

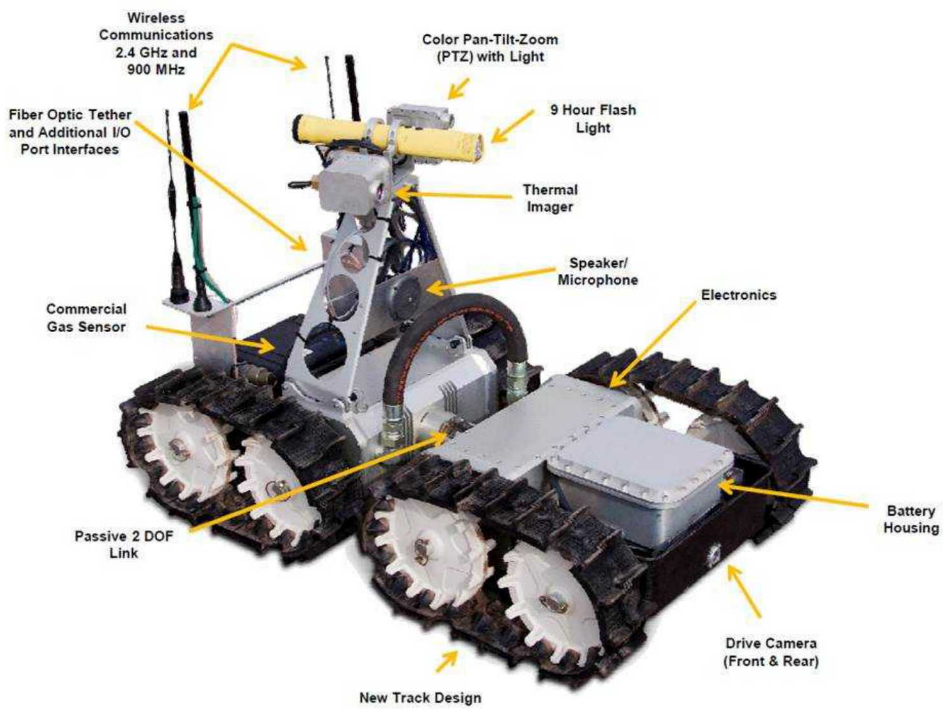

Figure 2. Major components of the Gemini Scout robotic vehicle.

The vehicle is controlled through an onboard computer running a custom build of an embedded control application. This embedded control application communicates directly with all the onboard components except for the audio and video systems. It also supports input from an Xbox360 controller (wired or wireless) connected to the vehicle allowing direct local control of the vehicle.

For teleoperation, an Operator Control Unit (OCU) is used to remotely control the vehicle via a wireless or tethered (Fiber Optic) connection. The OCU receives input from the operator via another Xbox360 controller (wired or wireless) and consists of a laptop computer connected via USB to a “communications hub” which houses a variety of components including an IP radio and audio encoder/decoder. All components of the OCU (shown in its operational configuration in Figure 3) can be powered by removable batteries or A/C power. The OCU software communicates with the vehicle through a single socket, sending commands and receiving vehicle status which is displayed on the OCU application’s graphical user interface (GUI). The OCU software also connects to, decodes, and displays the streaming video from the vehicle’s onboard video encoder.

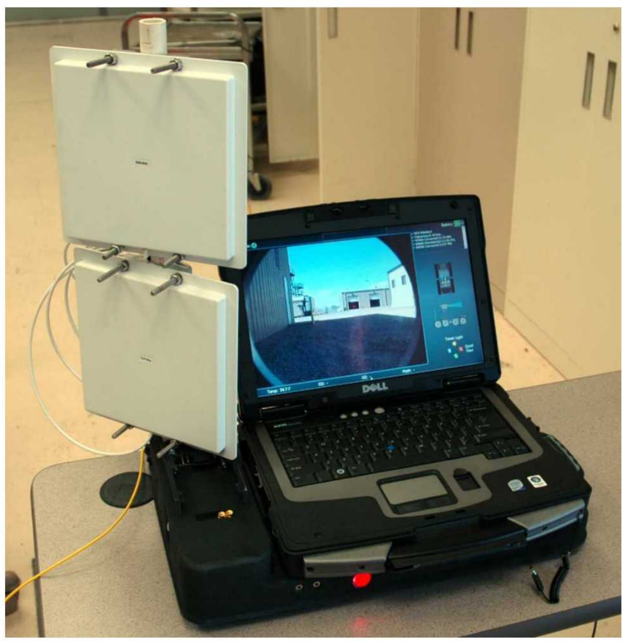

Figure 3. Gemini-Scout OCU with laptop running the GUI.

The OCU interface includes video as well as a graphical display of the tower pan-tilt position and the active camera view. This animated display updates in real-time as the tower pan-tilt moves. The functions of the colored face-buttons on the Xbox controller are also displayed graphically on the OCU window. The OCU interface also displays an array of status indicators including vehicle connection status, run time, connection type, wireless signal strength, battery level, and sensor readings. There is also a scrollable embedded message window that displays important system events along with the time each event occurred.

Communication between the OCU and the Gemini Scout vehicle is handled by a pair of radios providing a single two-way asymmetrical Orthogonal Frequency-Division Multiplexing (OFDM) wireless connection. The dual-band radios automatically transition between bands to maintain the strongest connection. This helps when operating in non-line-on-sight environments since the “dead spots” are often different for the two frequency bands. The radio performance is further improved by using antenna diversity on each frequency band on the vehicle. The vehicle thus carries a total of 4 high-gain Omni-directional antennae supporting this single data link. The OCU forgoes antenna diversity and instead uses a single (larger) directional antenna for each band (see Figure 3). The radio communication system includes detection of a wired connection which will automatically disable the wireless system and use the wired connection instead. Operating the vehicle in a tethered mode is a simple matter of making a connection between the OCU and the vehicle. If the tethered connection is lost for any reason during a mission, the radios will automatically try to establish a wireless connection to continue the mission or recover the vehicle.

Gemini-Scout’s current onboard sensing suite consists of a MSHA approved multi-gas sensor (O_2, CO, and Methane), internal and external temperature sensors, battery voltage sensors, color video cameras, and a forward thermal imaging camera. The layout of the sensors on the vehicle can be seen in Figure 4. The sensors run off a rechargeable Lithium-Ion battery.

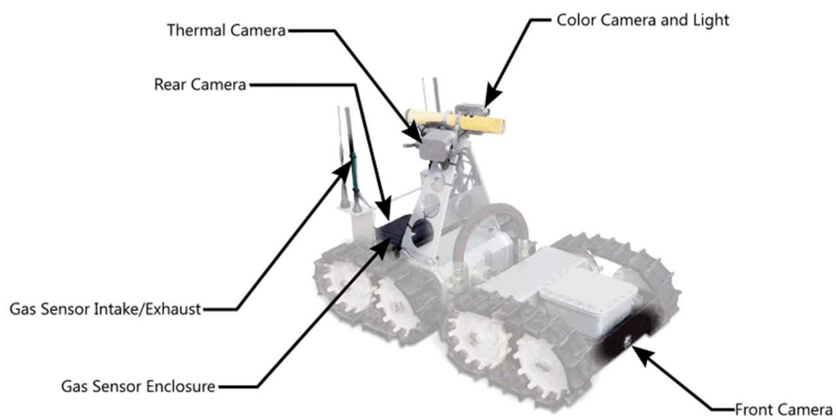

Figure 4. Gemini-Scout vehicle sensor layout.

Gemini-Scout has four camera feeds that can be transmitted individually or displayed at once. Two of the cameras are mounted at fixed locations to provide the operator with forward and rearward points of view. These cameras are the primary driving cameras. The remaining two cameras are located on an elevated pan/tilt unit. One of the cameras is a color zoom camera paired with a remotely operated spot light to ensure acceptable picture quality, and the other is a thermal imaging camera. The thermal imaging camera allows users to locate objects in low-visibility situations such as environments with low light or smoke obstruction. In the event of a fire, the thermal imaging camera will allow operators to locate individuals in need of assistance.

In addition to the integrated sensors in the Gemini-Scout design, several expansion ports have been provided on the exterior of the vehicle for future use. The design of the vehicle is such that integration of new sensors for new applications is supported.

The vehicle design for Gemini-Scout couples two identical tracked chassis together with a passive 2DOF pivot allowing for ±30deg of pitch and roll. The pivot allows the two chassis to rotate and pitch with respect to one another while maintaining a fixed yaw angle between the two bodies (critical for ensuring proper skid-steering). The passive joint allows Gemini to maintain four points of contact with the ground which enhances mobility through better traction.

For a battery powered vehicle to safely operate in a hazardous (gas) underground environment, it must either be intrinsically safe or explosion proof. The mechanical design of Gemini-Scout was developed following the guidelines for explosion proof design taken from Title 30 Code of Federal Regulations. These guidelines ensure that if the robot is operated in a hazardous gas environment and an internal spark ignites the gas contained by the vehicle housings, the fire cannot escape the housing and cause the external environment to ignite; potentially causing a secondary explosion that could harm rescue personnel or victims.

APPLICATIONS

The primary mission of this mine rescue aide is to act as a scout to help rescue crews move safely and efficiently through hazardous environments. This platform can readily be integrated with the necessary cameras, microphones, and sensors to act as the eyes and ears of the rescue crew while also providing valuable information about the air quality such as O_2, CO, and CH_4. All of this is done well in advance of the rescue crew keeping human first responders out of harm's way. While the primary mission of this vehicle is for mine safety, the application is universal to other hazardous, unknown, and potentially lethal environments. A properly outfitted vehicle is sent in to provide assessment information to first responders prior to a human entering the environment. This increases safety as well as decreases the time required to react to an accident or unusual event. If required, a vehicle of this type could simply follow first responders into an incident area on standby until needed by an operator.

Another potential mission for the rescue aid vehicle is to act as a pack mule while entering and exiting the mine. In this configuration, the Gemini-Scout vehicle would be configured as a pack mule to carry up to 250 lbs of equipment in addition to the cameras and other sensors. This would be accomplished by strapping the equipment to a custom gurney that is then either carried on top of or pulled behind the vehicle. Extra equipment such as tools, oxygen bottles, food, water, and medical supplies could be transported into the mine without endangering any more people than necessary.

Smaller versions of the same primary Gemini Scout design could be developed to support other applications. A smaller version of the Gemini Scout would be light weight (<50lb), nimbler for tight spaces, easier to portage over impassible terrain, use fewer batteries and be easier to stow and transport to/from rescue locations. The disadvantages are that it would have reduced mobility capabilities over large rubble piles and it would not be able to transport large amounts of equipment. This Mini-Scout vehicle concept is a viable option for serving not only the mining industry, but any number of communities to perform search and rescue, reconnaissance, and exploration.

TESTING

Using obstacles and terrain that can be expected in a mine accident, testing has been conducted to push the Gemini-Scout to its limits. Various tests simulating realistic environments for a mine accident scenario are shown in Figure 5 through Figure 8 Figure 8below. The results of this testing help form the concept of operations that will guide future decisions on how to use a robot in mine-rescue operations.

Figure 5: Gemini Scout robot operating in a water-filled dirt trench.

Figure 6: Gemini Scout robot operating over rough terrain and up a smooth surface.

Figure 7: Gemini Scout robot operating over a block rubble pile.

Figure 8: Gemini Scout robot driving through dry and wet rock dust.

LESSONS LEARNED

One of the goals in the development of the early version of the Gemini Scout robot was to provide a test platform which would allow end users to assess required features and operational requirements. The results of this evaluation will be used in future development projects of similar type. In summary:

- The two-body tracked design allowed the robotic vehicle enhanced maneuverability over obstacles and rubble;
- The Gemini-Scout OCU design allowed for simple and straightforward set-up;
- Operators could successfully maneuver the robot via the handheld controller after only a short training period;

- The waterproof design allowed function in standing water as well as in puddles of mud and wet rock dust;
- Explosion-proof design adds weight to the vehicle, but allows for operation in the presence of flammable or explosive dusts and vapors, greatly increasing the operating envelope of the robot.

Suggested enhancements include:

- Utilize an enhanced wireless communication or tie into existing communication infrastructure which would allow beyond line of sight capabilities;
- Incorporate an automatic retreat function in the event of loss of communication;
- Integrate the ability to save video during operation;
- Develop the ability to show an estimate of distance and/or path travelled during operation;
- Enhance video with the latest high-resolution cameras and lighting;
- Improve the track design;
- Optimize volumes to reduce size and weight as much as possible;
- Add additional robot state of health monitors and alarms at the user interface.

To be successful in certifying and fielding an operational remotely-operated vehicle for waste management scenarios, developers must engage with the funding organization, end users, and the certifying organization early in the design process. It is critical that a complete understanding of operational environment and requirements be developed. In addition, the use of formal design reviews with the funding organization, end users, and the certifying organization throughout the design process is recommended.

CONCLUSIONS

The Gemini-Scout is a rugged design giving an operator excellent mobility in unstructured environments. Its design is directly applicable to waste management. A Gemini-Scout-like vehicle, equipped with appropriate sensors could provide initial assessments after accidents or unexpected events. Some design changes including increasing the ground clearance, developing stiffer tracks, removing external connections by utilizing wireless communication, and minimizing empty volumes could make a next generation Gemini-Scout even more mobile and immune to external upsets which would provide even greater support in the field.

REFERENCES

1. Garretson, Justin, Hobart, Clinton, and Salton, Jonathon, "Gemini-Scout Mine Rescue Robot", prepared for AUVSI Unmanned Systems North America 2010, Denver, CO, August 24-27, 2010.

2. United States Department of Labor – Mine Safety and Health Administration: Code of Federal Regulation 30, Parts 1-199 (Mineral Resources). http://www.msha.gov/30cfr/0.0.htm