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Unmanned and Unattended Response Capability for Homeland Defense

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Abstract

An analysis was conducted of the potential for unmanned and unattended robotic technologies for forward-based, immediate response capabilities that enables access and controlled task performance. We analyze high-impact response scenarios in conjunction with homeland security organizations, such as the NNSA Office of Emergency Response, the FBI, the National Guard, and the Army Technical Escort Unit, to cover a range of radiological, chemical and biological threats.

We conducted an analysis of the potential of forward-based, unmanned and unattended robotic technologies to accelerate and enhance emergency and crisis response by Homeland Defense organizations.

Response systems concepts were developed utilizing new technologies supported by existing emerging threats base technologies to meet the defined response scenarios. These systems will pre-position robotic and remote sensing capabilities stationed close to multiple sites for immediate action. Analysis of assembled systems included experimental activities to determine potential efficacy in the response scenarios, and iteration on systems concepts and remote sensing and robotic technologies, creating new immediate response capabilities for Homeland Defense.

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Introduction

An analysis was conducted of the potential for unmanned and unattended robotic technologies for forward-based, immediate response capabilities that enables access and controlled task performance. We investigated the evolving needs of homeland security organizations, such as the NNSA Office of Emergency Response (OER), the FBI, the National Guard, and the Army Technical Escort Unit, to cover a range of radiological, chemical and biological threats. We also worked with Army Explosive Ordnance Training (EOD) Department, which trains National Guard units. We then developed a conceptual high-impact solution to issues common between the organizations. This solution included pre-positioning robotic and remote sensing capabilities stationed close enough to multiple potential domestic target sites to enable immediate, ground-deployed action.

The NNSA OER has the responsibility to respond to radiological and nuclear threats, both hostile and accident situations. Traditional functions include crisis response, as well as consequence management post-attack. National Guard Weapons of Mass Destruction Civil Support Teams (WMD-CST) are intended to assist civil authorities by responding to a domestic weapon of mass destruction incident, and should possess the requisite skills, training and equipment to be proficient in all chemical, biological, nuclear and radiological mission requirements. The Army Technical Escort Unit has responsibility for chemical weapon threat response, determining what the device may be and appropriate handling methods. The FBI has general responsibility for countering domestic terrorism, and is currently building capabilities to coordinate responses to WMD threats.

The following conclusions have been drawn from these organizations:

- Response assets should be based on threat and located to respond rapidly to major population centers.
- Perception of the current threat is evolving toward more sophistication, indicating a large degree in solution flexibility is desirable.
- Search and ID must be given the highest priority possible.
- Search needs to be conducted and/or coordinated by Radiological Assistance Program (RAP)/CST/local responders depending upon the type of threat and team proximity.
- Robotics are becoming more desirable as devices become more deadly to the disposal technicians.
- An EOD reach back for WMD needs to be developed for police bomb squads, CST, FBI and other Federal assets for support when highly-sophisticated devices are discovered.

Conceptual Solution

To meet the needs identified in this analysis, forward-based, remote, unmanned robotic technologies can be used. One concept for consideration is to enable the existing fleet of EOD robots currently deployed around the USA to execute more advanced operations, more easily and quickly than currently possible. Armed with new tools and sensors, pre-deployed robots in the population centers of the U.S. would be able to quickly remotely access buildings and vehicles, find the target object, and stabilize the situation or render safe the device. They would be used routinely by civilian law enforcement and HAZMAT responders, and have the ability to be "federalized" with additional sensors, communications and personnel support.

Approximately 200 EOD remote controlled vehicles (RCV) are currently deployed in civilian law enforcement agencies in population centers, with another 200 in military hands in the U.S. and abroad. Further, Sandia National Laboratories has demonstrated through this LDRD and other activities that the control systems of 80% of these vehicles can be upgraded with commercial off-the-shelf (COTS) equipment and specialty software to provide simultaneous improvement in sensing, mobility, manipulation and ease of use.

To enable this concept, a number of technologies are required. These include:

- Sensing
  - Chemical
  - Explosive
  - Radiation (field detection, spectrum and contamination)
  - X-ray
- Model building
  - Enables understanding and analysis of current environment
  - Utilizes data from available sensors
- Human-machine interface
  - Enables intuitive, easy interaction with models and analytical tools, as well as machine tasking/control.
- Path planning
  - Automated planning and execution of actions selected by an operator
- Communications
  - Effective short range communications from local operator to robot/sensor platform
  - Effective long range communications to support personnel/resources
- Modular control architecture
  - Enables flexible technology integration
  - Rapid system integration
- Good machine design

- Maneuverability
- Dexterity
- Sufficient accuracy and repeatability

Many of these capabilities have been demonstrated at Sandia National Laboratories in the Intelligent Systems and Robotics Center. They have been tested in the laboratory and taken to the field for experiments by FBI and Military users. The following section describes experiments at Ft. Leonard Wood, where National Guard Civil Support Teams are now being trained.

Robotic Manipulation Experiments at the U.S. Army Maneuver Support Center

This activity brought two robotic mobile manipulation systems developed by Sandia National Laboratories to the Maneuver Support Center (MANSCEN) at Ft. Leonard Wood for the following purposes:

- Demonstrate advanced manipulation and control capabilities,
- Apply manipulation to hazardous activities within MANSCEN mission space,
- Stimulate thought and identify potential applications for future mobile manipulation applications,
- Provide introductory knowledge of manipulation to better understand how to specify capability and write requirements.

Equipment Description

The Wolverine robot is a commercial product from REMOTEC, similar in size to the RONS vehicle currently deployed with U.S. military Explosive Ordnance Disposal (EOD) forces around the world. Hardware was modified by complete replacement of the control system with a PC-based controller and joint angle sensors. The manipulator is mechanically identical to the most recent RONS upgrade, with 5 degrees of freedom (DOF) and a redundant linear joint.

The Turing robot is built on a chassis similar to the Bison robot deployed by U.K. military EOD forces in Bosnia and Kosovo, with a 6 DOF experimental manipulator of greater dexterity and speed than the Wolverine.

Visual targeting was installed on both robots, enabling automatic operations against operator-designated targets. Hardware includes a pair of calibrated cameras mounted on a pan-tilt unit on the robot. Video images are sent to the operator, who draws on the video screen to convey target information to the robot system.

The control station, located in a trailer that doubles as garage and repair station, consists of 2 industrial PC computers, a flat screen video display, a flat screen

"soft" control panel, and a variety of selectable input devices. Input devices include joysticks, space ball (a 6-DOF single-hand device capable of controlling the entire manipulator) and foot pedals used for steering and acceleration.

The entire system was integrated and enabled using the Sandia Modular Architecture for Robotics and Teleoperation (SMART) tools. SMART enables access to the broadest range of hardware and software technologies while substantially reducing integration time and time to field for systems requiring real-time operation. In addition to more capabilities, SMART also facilitates more efficient use of existing capability and substantial improvement in ease of control. SMART is also compatible with the Joint Architecture for Unmanned Ground Systems (JAUGS).

Demonstration Description

Each of the MANSCEN schools – Engineer, Chemical and Military Police - was tasked to identify difficult and hazardous activities within their mission space and bring training aids against which to experimentally apply mobile manipulation robots. Each school was provided two days with the robots, during which the soldiers were trained to use the robots' advanced manual control and automatic control capabilities, and the experimental tasks were carried out. Little or no advanced information was provided to the SNL robotics team prior to arrival at MANSCEN, thereby challenging the flexibility of the robot systems. Detailed descriptions of the tasks and results are provided below.

Combat Engineers

The engineers challenged the system to locate a buried mine using a standard hand-held mine detector, cut any trip wires attached to the mine, then remove the fuse from the mine. In experiments associated with breaching, emplacement of charges, breaching frames and shotgun aiming was required. The ability to hold and fire weapons was also on the requirement list; holding and aiming was demonstrated. Finally, an experiment in placement and aiming of an explosively-formed penetrator was carried out.

Mines

Locate buried mine

The challenge was to robotically sweep an area to find mines, un-exploded ordnance (UXO) and a proofing wire using a hand-held mine detector. With no modification and mounting on the Wolverine robot using tape, the mine detector was useable with the audio signal passed from headset to the robot microphone and on to operator. Items as small as a 2 cm length of wire were detectable. Multiple mines and metal objects such as a 20mm shell were detected.

Future demonstrations could include automatic sweeping patterns that could be readily programmed. Sensors to maintain distance from ground would be desirable. Non-intrusive sensors such as laser ranging may be best to prevent interference with magnetometry, but light-based sensing may be limited in tall grass and shrubs.

Defuse anti-tank mine

Using the Turing robot, engineers removed the fuse of a training device within about 40 seconds of coming within reach of the device. On the second attempt, the gripper was forced down between fuse and mine body, wedging fast and burnt out a small rotation motor in the wrist. Turing was running after a 3-day wait on replacement parts.

Future demonstrations could include use of a force-torque sensor to prevent over-torque of devices and robotic equipment. Specialized tooling may be necessary to clear soil and debris from around fuses.

Defuse anti-personnel mine

Using the Wolverine robot, engineers were able to remove a fuse from an anti-personnel (AP) mine by reaching over the fuse, under the tilt mechanism with blocks taped to the gripper, and rotate it free. The blocks were necessary because the gripper configuration did not allow sufficient clearance around the triggering mechanism.



Anti-tank mine defused



AP mine defused



Mine sweeping

Trip wires

Using the Wolverine robot, engineers removed 15 trip wires using dikes taped to the gripper. Two mines were buried in soil with trip wires reaching away from the fuse with light camouflage. These wires could be seen clearly through the robot

color zoom camera. In many trials, each wire was cut within minutes. Most cuts would not have detonated the mine in the judgement of the observing engineers.

In one experiment, visual targeting was used to mark all of the wires attached to the fuse. The operator could then command the robot to approach within approximately 8 inches automatically, and take over manually for the cut. Depth perception for the operator was difficult for wire cutting, slowing the general process.

Laser-line cross hairs normally used for bore sighting were tested for the ability to see trip wires in air. Shiny wires can be seen as red dots in the air disconnected from the remainder of the projected line in indoor light. Rusted wires can also be seen. In darkness, trip wires stood out clearly in the robot video cameras. Scanning the laser showed the wires as points moving linearly toward or away from each other in space.



Devices for test include mines, UXO and fuse igniters.



Mines buried with trip wires



Trip wires cut by robot



SFC O'Donoghue conducts robotic countermine activities at the OCU.

Future demonstration: The trip wire visibility in this experiment indicates that use of a laser scanning system such as SNL's LAMA system (part of which is already built into the demonstrated robots' targeting system) could be used to automatically identify linear segments of trip wires in both daylight and darkness. Higher accuracy sensing and manipulator systems could produce an automatic wire cutting capability, eliminating the difficulty with operator depth perception. Visual servoing technology, currently under development at SNL, could be used

to guide the cutters onto the wire. Alternatively, the stereo camera system could be utilized to bring back stereo imaging for the operator's eyes.

Charge Placement

Placement of explosive charge

An EOD-type general disrupt device (mineral water bottle charge) was emplaced near multiple objects using manual and automatic techniques. Automation provided the tool change capability, retrieving the charge from a storage location by a button push.

Automation was also used after the operator visually targeted the package to be destroyed, illustrated in the photos below. The robot placed the charge in the optimal position automatically upon operator command. Shock tube for initiation was payed out as the robot backed away from the device.







Clockwise from top: Operator visually targets device by drawing a line at the base of the object on the video screen, thus telling the robot the position and orientation of the object of interest and the ground; Operator automatically retrieves disruption charge by pressing "Retrieve Waterbottle" button; Operator automatically emplaces the charge by pressing "Place Waterbottle" button.

Placement of EFP

An explosively-formed projectile (EFP) was emplaced using the Wolverine robot. The EFP was pre-mounted on a tripod that was retrieved and placed using the

robot. Final aiming was difficult using the manipulator, due to the two-handed nature of the tripod adjustment mechanisms, requiring simultaneous loosening/tightening of tripod knobs and the movement/holding of the EFP unit in position. The robot wrist camera was adequate for the aiming process. However, the aiming required significant iteration between moving the EFP, releasing it, moving the camera into position to see the aim, and repeating the adjustment until the aim was satisfactory.

Future demonstration: A new form of placement with a single-action adjustment is needed. Such a device would be beneficial for many military and civilian charge placement activities. Visual targeting could be used for target designation, and visual servoing technology utilizing external references could be used to align an arbitrarily-gripped device to the target.



EFP retrieved (left) and emplaced (right)





OCU during EFP placement

Breaching Frames

Engineers emplaced breaching frames for explosive breaching. Frames, normally lined with explosive and filled with water for tamping were recovered from the floor using the Wolverine robot under telerobotic control and emplaced against doors and walls. Initiation would be provided by a shock tube identical to that used in the charge placement demonstration. A stick to prop the frame against the wall was not used but provided for normal operations.

Future demonstration: Retrieving and emplacing the larger frame when full of water and propped by the stick would demonstrate the strength of the robot and any issues associated with propping the frame against the wall prior to backing away to a safe distance with the robot.









Clockwise from left: SFC Rostad operates robotic breaching process; recovering frame from floor; movement toward target; emplacement at target.

Weapon aiming

The Woverine robot is designed to aim and fire gun-type weapons. A percussion-actuated, non-electric (PAN) disrupter was mounted to the side of the manipulator and aimed automatically at a pipe bomb using the visual targeting techniques. Bore-sighted laser crosshairs, developed at SNL and mounted on the PAN, enabled the operator to verify proper trajectory and impact point prior to firing.

A shotgun for breaching was also held in the gripper to demonstrate sufficient dexterity for shotgun breaching. Breaching operations may include engaging

steel concrete-reinforcement bars with the barrel and firing a cutting projectile. Shotgun mounts for the Wolverine are sold commercially.

Future demonstrations could include automatic aim verification using visual servoing technology. The system would then automatically check the bore alignment with the target point and trajectory, and automatically adjust the aim to simplify the operation.



To shoot an object using visual targeting, the operator draws a line on video screen stereo images indicating target object, position and orientation to the robotic system.



Wolverine targets a pipe bomb automatically after visual targeting.



Shotgun is held in the gripper for breaching dexterity demonstration.

Military Police

Perimeter sensor emplacement

Military Police (MP) are charged with security of a maneuvering column in the field. Securing a perimeter is one of their missions. The MPs had seen the Perimeter Detection System demonstrated by SNL, using Miniature Intrusion Detection System (MIDS) sensors in conjunction with man-packable mobile sensor platforms that provide automatic alarm investigation with or without a soldier in the loop. Their challenge was to demonstrate that this could be set up using mobile manipulators to eliminate the need to expose a soldier to potential hostile fire or other hazards.

To demonstrate this, a MIDS magnetometer sensor was retrieved from a storage location on board the Wolverine robot and set near the emplacement site. The Wolverine manipulator then excavated a shallow hole, placed the sensor in the hole and covered the sensor.

Future demonstrations could include emplacement of a larger suite of sensors, including multiple magnetometers, seismometers, passive and beam-break infrared sensors. Smaller, marsupial (piggy-back) mobile sensor platforms could also be deployed from the manipulator platform, and the entire system activated. Finally, the entire perimeter protection system could be serviced or retrieved by the manipulator platform and transported to its next location.

Charge placement

The disruption charge placement demonstration described above for the Engineers was repeated by the MP contingent.

Weapon aiming for IED disposal

The weapon aiming demonstration described above for the Engineers was repeated by the MP contingent.

Covered object inspection

Using the Turing robot, MPs removed a tarp from a “suspicious package” in order to investigate and retrieve the package. The tarp was weighted by objects on top of its edges which were removed remotely. MPs then grasped the tarp with the robot manipulator under manual control and dragged it from the pile of objects. The operator then remotely approached the package under manual control, and repeated the operation under automatic control after visually targeting it as described above.



MP operator removes a tarp from a group of covered objects using the Turing robot under manual control.



SSG Steltenpohl operates the Turing robot in an object inspection and recovery task.

Building access: door opening

Accessing buildings for emergency response and inspection activities requires manipulation capability. MPs requested a demonstration of how to open building doors so that the robot could pass into and out of a building without damage.

The Robotic Technology Integration Activity (RTIA) main building provided the door for the building access door demonstration. The door was approached from both sides to demonstrate both inward and outward swing. The unlocked door was opened using the Wolverine robot in less than 2 minutes in each direction. Passing through the door from the direction toward which the door swung was not possible due to the automatic closure device and a lack of auxiliary equipment to prop the door open (such as the articulating tracks on the EOD RONS robot).

Future demonstrations could include unlocking and relocking the doors with keys. The fundamental capability to insert keys in keyholes and turn the lock has been demonstrated at other venues with improvised tooling. Rapid insertion could be better accomplished using force-torque sensing at the wrist and visual servoing for initial alignment.

Vehicle access: truck door opening

Accessing vehicles for inspection and emergency response purposes also requires manipulation capability. The Wolverine robot was used to open a push-button latch on a pick-up truck door. The truck door, with a push-button type handle, was open within 30 seconds of the robot arriving within reach of the door handle. The primary difficulty was depth perception; the time required to determine when the robot was within reach of the handle was increased by several attempts to reach the door when the robot chassis was not parked within manipulator range.

Future demonstrations could include the use of reachability analysis software that indicates to the operator whether a particular object is physically within reach of the object of interest (e.g. a door handle). Such software exists at SNL, including the ability to indicate where the robot must go in order to reach an object. It has not yet been implemented on the class of robots used in this demonstration. Visual servoing capabilities under development could then maneuver the platform for appropriate manipulator positioning, then properly align the manipulator and key.

Chemical Corps

The Chemical Corps was interested in the possibility of automating many of the difficult manual operations associated with the Fox vehicle, as well as chemical and radiological agent detection and sampling.

Fox Vehicle Activities

The Chemical Corps wished to explore the possibility of mounting a robot manipulator on the rear of a Fox vehicle to execute many of the operations currently done left-handed through a single glove port mounted too high in the vehicle to reach the ground.

Most of the operations in question could be demonstrated immediately. Some minor modifications to equipment and processes would be advised in the event that robot manipulators are used that would greatly streamline the processes and enable more processes.

Soil and Biological Sampling

Soil and biological samples are normally taken manually through a glove port in the back of the vehicle. In order to reach the ground, a tool drawer containing a set of tongs must be opened, the tongs retrieved, a plastic vial retrieved from a holder and opened, a sample scooped from the ground into the vial, and the vial closed and placed into another holder on the back of the vehicle, all with the left hand.

The Turing robot was used to scoop a sample and place the vial into the Fox sample holder as shown below. Opening the drawer for the tongs was not necessary, as the robot itself could reach the ground. Opening and closing the vial was not possible using only the manipulator. However, clever engineering could provide a means of securing the vial and opening the lid.

Future demonstrations could include gripper modification to permit a more firm grip on the slippery sample vials, as well as a lid holder and modified lid attachment approach that would simplify the sampling and sealing process. A small “plug” excavating tool may also improve the sampling process. Sensors for automatically locating the ground and for controlling force and torque during sampling, in conjunction with existing path planning software, would provide an automated means of sampling soils.









Clockwise from top left: SSG Smith executes robotic soil sampling; Turing robot retrieving soil from stony terrain; Sample vial is placed into Fox vehicle sample holder; Insertion of vial into sample holder completed.

Temperature Probe

A temperature probe is also located in the drawer described above. The Turing robot opened the drawer (but not the latched door covering the drawer), removed the probe and inserted the thermal sensor into the soil.

Future demonstrations could include automatic retrieval of tooling. Insertion of probes would benefit from force-torque sensing to prevent damage to the probe during an automatic insertion. Visual targeting could also be used to indicate multiple positions for automatic probe insertion, and result in automatic mapping of the thermal data to positions.





Turing robot opens the Fox vehicle tool drawer (above), removes the thermal probe, and places it into the soil (right).

Sample Wheel Replacement

Small sampling wheels are rolled along the ground behind the Fox vehicle to collect running chemical samples. Periodically, they must be removed and heated to desorb the sample for analysis in a gas chromatograph. Currently, the glove port described above is used to single-handedly remove the wheel and place it into the heating chamber. A new wheel is then installed on the axle and returned to the ground.

The Turing robot had sufficient dexterity to remove and replace this sample wheel, and the operation was demonstrated three times. Executing the replacement operation using manual control was both difficult and time consuming, even with the advanced control capabilities. Releasing the hub clip

from one side of the wheel was not possible using the single manipulator. Several possibilities for improving the wheel clip design were discussed that would both enable robotic manipulation and simplify the gloved manual operation.



Sample wheel with hub clip released.



Sample wheel removed.



Turing robot removing sample wheel.



Turing robot replacing sample wheel.

Future demonstrations could include a manipulator fixed to the Fox vehicle, with pre-programmed positions and orientations for wheel removal and replacement. Tapering the hub of the wheel and altering the hub clip would enable easier robotic and gloved-hand replacement.

GB and Mustard Gas Surveys

This operation utilized the Wolverine robot with a CAMSIM detector used to train Chemical Corps soldiers to detect simulated nerve and mustard agents. The demonstration required both area sampling as well as close-in scanning detection techniques.

The CAMSIM detector was retrieved from a tool holder on the robot, then deployed near simulated agent on objects and on the floor. Samples could be detected only if the detector was within about ½ inch of the sample. Therefore, scans were made maintaining the ½ inch distance from the vertical and horizontal surfaces until detection was made. The operator could view the detection window of the sensor through the robot wrist or mast video cameras.

Future demonstrations of the scanning process could include visual targeting for the operator to designate an object, its volume and surfaces to scan. Path planners are available to generate the scan pattern, which can be automatically executed. The infrastructure necessary to streamline and automate this process is in place, requiring relatively minor development to enable automatic scan generation and execution.





Wolverine automatically retrieves detector from storage location (left) and scans across the container above at ½ inch stand-off without collision until it detects the simulated agent near the floor.

A contamination simulant representing off-gassing material was placed in the building and the robot operator was required to locate it. The sample was located in a bathroom, and was detected as the robot manipulator reached through the door. Again the operator was able to see the sensor read-out through the robot mast and wrist cameras.

It is important to note that to access buildings, rooms and vehicles for scanning it is necessary to have manipulation capability. Vehicle sensor platforms cannot

otherwise enter such areas unless escorted by humans, which in turn puts humans at unnecessary risk.



Wolverine robot executes area scan for mustard agent, detected from a distance of approximately 4 feet.

Liquid Sample Testing

Liquid samples may be tested using a paper detector that changes color in the presence of certain agents. To demonstrate this, the robot retrieved a sample paper and placed it rapidly into a puddle on the floor near a “leaky” container. The color zoom camera on the Wolverine mast was able to see the paper and any color change clearly.

Future demonstrations could include liquid recovery and insertion into analytical equipment, utilizing both teleoperation and automatic capabilities.

Radiological Surveys

A contact radiological swipe was taken using the Wolverine robot. A sample paper was attached to a block of wood to provide stability, which in turn was attached to a spring-loaded cylinder via hook-and-eye material. Under manual

control, the Wolverine retrieved the sample paper, placed it on a container, and swiped approximately 100 sq. cm. of the surface. At the push of a button, the robot then automatically placed the paper into a container mounted at the side of the robot, where it was released under manual control.

Future demonstrations could include placement of the samples into a spectrometer for contamination identification. A version of this was done by SNL in the mid 1980s using robots to arbitrarily choose points on a spent nuclear fuel transport cask, swipe the surface and analyze for contaminants using a modified Canberra machine.







Block-mounted sample paper is attached to a spring-loaded tube for radiological contamination swipes (top left); Wolverine robot executes surface contamination swipe; swipe is deposited in container on robot for later analysis.

Explosive Ordnance Disposal

In addition to the planned School activities, EOD soldiers posted at Ft. Leonard Wood also participated in demonstrations as a part of the MP group. The soldiers were trained in fundamental control of the robots in manual and automated modes, then executed the access and disruption activities described in Section 3 above.

Conclusion

Most challenges brought to the demonstration by MANSCEN were achievable with little training and some improvisation. All tasks were accomplished under non-line-of-sight (NLOS) conditions. With less than 1 hour of training, each soldier had a fundamental knowledge of the robot capabilities, and was capable of controlling the robots in both manual and automated modes. Within another hour, the comfort level with the robots had risen such that substantial increases in operational speed and creative use of the capabilities could be observed.

Standard hand tools and weapon configurations were utilized for the demonstrations. Modifications to the tooling for robot deployment consisted mainly of adding tape and wooden blocks or hook-and-loop material for gripping and mounting purposes. Robot-mounted cameras permitted visual reading of the detection devices, and the on-board microphones enabled audio feedback from the mine detector to the operator.

Written feedback from the soldiers was provided directly to Robotic Test and Integration Activity (RTIA) personnel. Verbal feedback from the soldiers indicated a general belief that these and many other operations could be carried out using mobile manipulation systems with similar dexterity. Different reach and payload capacities may be necessary in future activities. All commented on the ease with which they could learn to use the robot. Most indicated that the space ball input device, after some practice, was the most efficient means of controlling the manipulator. This can be done with one hand, with inputs interpreted into straight-line motion of the tool tip in cardinal directions, which the soldiers confirmed is a very intuitive motion resulting in faster execution of operations.

EOD soldiers were the most vocal about the improvement of capability and robot control. Familiar with the currently-fielded RONS vehicle, they were adamant that the ease of control and improved dexterity of the demonstrated robots is the direction the Army must take.

This demonstration was a preliminary step in experimental use of manipulation in the MANSCEN mission space. It is apparent that a limited set of small, medium

and heavy manipulators would be useful in executing many difficult and hazardous tasks both current and future. SNL looks forward to the opportunity to work with the Army to develop efficient, easy to use mobile manipulation systems to meet the challenges of the interim and objective forces.

The need for unmanned and unattended response capability is becoming increasingly clear. The capabilities integrated and demonstrated during this effort and at Fort Leonard Wood demonstrate the ability to meet these needs with available and soon-available technologies. Key efforts will include field hardening of machines, communications and data optimization, further development of the human-machine interfaces, and further integration of environmental sensors and automatic planning/programming.

Additional Work

Communications will need to be enhanced to provide visual and sensory data up-linked to federal support assets. An experiment of this nature was conducted in this LDRD effort to show how an EOD robot can send data from the scene through satellite communications to other locations where subject matter experts can analyze the data in real time and provide recommendations directly to the technicians on site. This experiment indicated the need to research maximizing the effect of data transmitted on narrow bandwidths, the need to coordinate the feedback from multiple analysts, and the possibility of the subject matter expert to temporarily “take over” the field asset either for analytical purposes or to recover from dangerous situations.

Further activity based on these efforts will be pursued through the contacts developed in this LDRD. Demonstrations were scheduled in October 2002 for potential civilian users. The Army EOD School commander at Redstone Arsenal has expressed very strong interest in acquiring the capabilities described above for Army EOD forces, and has arranged for an opportunity for live demonstrations at Redstone Arsenal in December 2002. Due to its proximity and formal ties with the Army EOD School, personnel from the FBI Hazardous Devices School will also be participating in this demonstration. This combination represents a significant portion of the U.S. training for weapons of mass destruction both domestically and abroad.

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