TECHNICAL REPORT 1839
November 2000

Robotics for Law Enforcement: Beyond Explosive Ordnance Disposal

H. G. Nguyen
J. P. Bott

Approved for public release;
distribution is unlimited.

SPAWAR
Systems Center
San Diego

SSC San Diego
San Diego, CA 92152-5001

SSC SAN DIEGO
San Diego, California 92152-5001

Ernest L. Valdes, CAPT, USN
Commanding Officer

R. C. Kolb
Executive Director

ADMINISTRATIVE INFORMATION

DISCLAIMER

EXECUTIVE SUMMARY

Mobile robotics has matured quickly in the past decade, with more and more robots entering practical field service. The two most active application areas for mobile robots so far have been military and law enforcement. For law enforcement, most activities to date have been in the area of explosive ordnance disposal (EOD), where robots are used to keep the human bomb disposal expert out of harm's way. In 1999, the National Institute of Justice (NIJ) funded the Battelle Memorial Institute to perform a survey on the desired attributes of an EOD robot. In addition, NIJ funded the Space and Naval Warfare Systems Center, San Diego (SSC San Diego), to assess law-enforcement needs for robots beyond EOD and identify technologies from Department of Defense (DoD) robotics projects that can help meet those needs.

To establish law-enforcement needs for non-EOD robots, we conducted a web-based survey over a period of 8 weeks, hosted on our SSC San Diego Robotics web site. The survey addressed scenarios and tasks where a robot would be used if available, and the tools, features, and parameters deemed most important to carry out those tasks. It also solicited respondents' experiences with currently available robots. The survey was publicized by electronic mail to over 200 state and local law enforcement agencies.

To identify DoD robotics technologies that could contribute to the development of law-enforcement robots, we conducted face-to-face, telephone, and e-mail interviews with personnel from the Unmanned Ground Vehicles/Systems Joint Project Office (UGVS/JPO) and the Defense Advanced Research Projects Agency (DARPA). With leads from these funding and program-management agencies, we contacted various DoD robotics research and development activities and their contractors.

We presented results from the two surveys. In particular, we found that the law-enforcement community placed the most emphasis on having robots perform the functions of small-item delivery, passive remote communication, and remote surveillance. Features of a robot that were viewed as most important include stair-climbing ability, a robust communication link, low cost, and longer battery life. Most of these requirements are being addressed by the DoD activities surveyed. Solutions for other requirements can be found in the commercial sector or are being sought by the scientific community for applications outside robotics.

We concluded that there would be no single robot that would meet all the demands of law enforcement beyond EOD, and recommended the development of two classes of robots, separated by size. Each robot should be modular, with application-specific mission packages or tool sets that can be tailored to the needs of a specific user. We also outlined a proven, user-centric, phased, rapid-prototyping approach for a successful robotics development program. Finally, we recommended that NIJ personnel continue to maintain close liaison with DARPA and the Joint Robotics Program (JRP), and obtain input from JRP in the technology assessment, source selection, and development of robotics assets.

CONTENTS

Figures

Tables

1. BACKGROUND

Mobile robotics has matured quickly in the past decade, with more and more robots entering practical field service. The two most active application areas for mobile robots so far have been military and law enforcement. For law enforcement, most robotic activities to date have been in the area of explosive ordnance disposal (EOD), where robots are used to keep the human bomb disposal expert out of harm's way. In 1999, the National Institute of Justice (NIJ) funded the Battelle Memorial Institute to perform a survey on the desired attributes of an EOD robot (reference 1). In addition, NIJ funded the Space and Naval Warfare Systems Center, San Diego (SSC San Diego), to assess law-enforcement needs for robots beyond EOD and identify technologies from Department of Defense robotics projects that can help meet those needs. This report presents the results.

2. LAW-ENFORCEMENT NEEDS

2.1 SURVEY PROCEDURE

To establish law-enforcement needs for non-EOD robots, we developed a questionnaire in early May 2000. We then met with members of the Los Angeles Sheriff Department's Special Enforcement Bureau (LASD-SEB) to discuss this questionnaire. From the feedback we received, we decided to convert this questionnaire into a web-based survey. Participants used radio buttons and check boxes to answer most questions, which helped the response process.

We let the web-based survey run for 8 weeks, hosted on our SSC San Diego Robotics web site (reference 2). The survey was publicized by electronic mail to over 200 state and local law-enforcement agencies whose e-mail addresses were found at various law-enforcement web sites (references 3 through 6). The National Tactical Officers Association also posted a link to our survey on their web site (reference 7).

Responses were converted to text messages by a Perl-script program residing on the web server and were forwarded to another computer for storage. When the survey was completed, a C program combed through the stored messages, tallied up the responses to each question and generated summary tables. These tables were then entered into an Excel® spreadsheet, which generated the charts in this report. The individual messages were also printed out and examined to extract manually entered information (from the "other information" or "notes" and "comments" fields), and to gain insight into unusual answers or unexpected groupings.

The survey has five parts. Part 1 establishes the respondent's background. We were interested in knowing how a respondent's familiarity with law-enforcement robots correlates with the actual responses. This hopefully will help us separate long-term desires and goals from more practical, short-term needs as would be reflected in the responses from those with more experience with robots. Part 2 examines scenarios where robots would be used, the tasks they would perform, and the tools required to accomplish those tasks. Part 3 discusses the features and parameters considered important on the corresponding robots, and part 4 solicits experiences with currently available robots. Part 5 asks a short question to establish the law-enforcement community's interests in various types of mobile robots.

2.2 SURVEY RESULTS

We received 65 responses from our web survey. Some were direct responses from law-enforcement agencies to our e-mail solicitations, others were from law-enforcement officers who found links to our survey at various web sites. Figure 1 shows the geographic origin of the responses superimposed on a U.S. population density map.

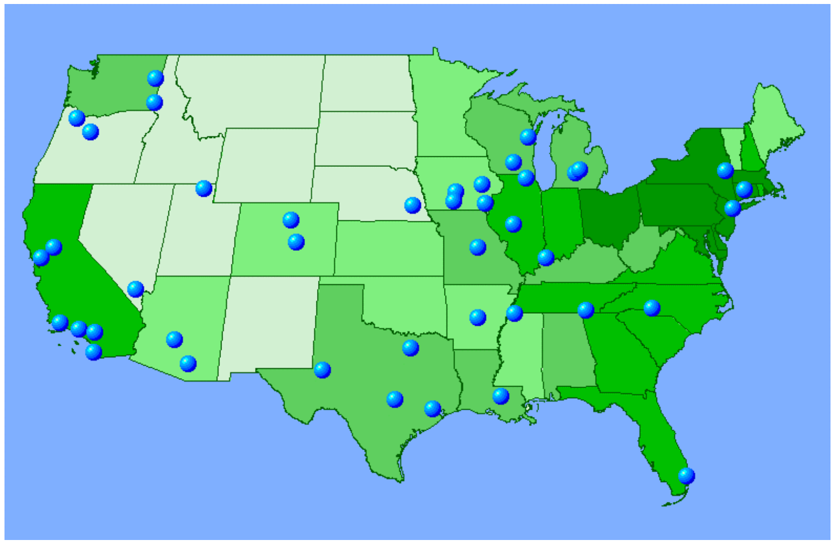

Figure 1. Geographic origin of survey responses.

Below is a summary of survey answers presented as charts to help visualize comparative significance. Appendix B contains the tabulated results, excluding personal information.

2.2.1 Specialties

Almost half of the respondents were members of the tactical community. Figure 2 shows the specialties indicated on the survey returns.

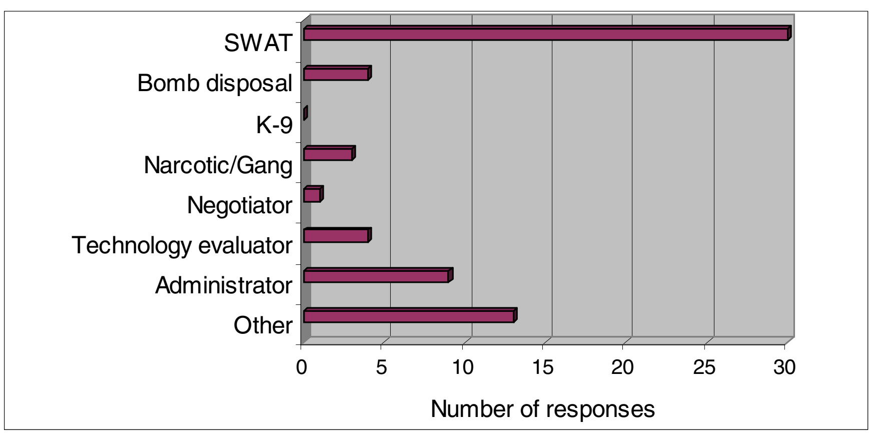

Figure 2. Specialties of respondents.

2.2.2 Robotics Experience

Figure 3 summarizes the respondents' experience with robots. Over 50% of the respondents had no experience with robotics. No respondent reported having a non-EOD robot only.

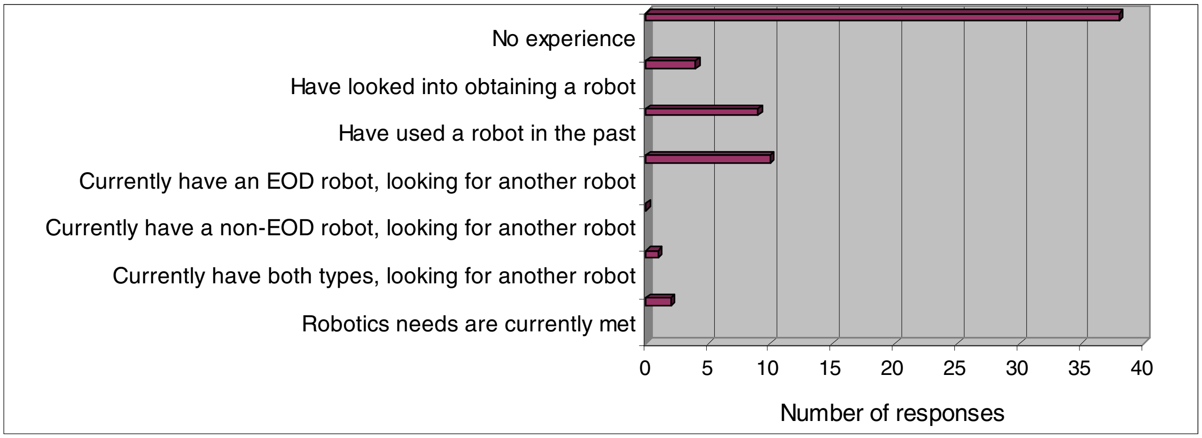

Figure 3. Robotics experience among respondents.

2.2.3 Scenarios

Inspection of hazardous areas and dealing with *barricaded suspects* ranked highest on the list of scenarios where a robot would be used if available. *Serving high-risk warrants*, identified during the initial meeting with LASD-SEB, was not considered appropriate for robotics by most respondents. Figure 4 rates the four scenarios provided in the survey questionnaire. The horizontal axis compartmentalizes the percentages of the missions when a robot would be used if available, and the vertical axis represents the number of survey responses picking those percentages.

Other scenarios that were mentioned included (each by one respondent):

- Reconnaissance in tunnels and storm drains (at U.S. ports of entry)
- Searching for criminals and lost persons
- Acting as hilltop repeater
- Site security
- Public reception and information dispenser
- Remote supervision
- Act as hostile element in training
- Dealing with suicidal subjects

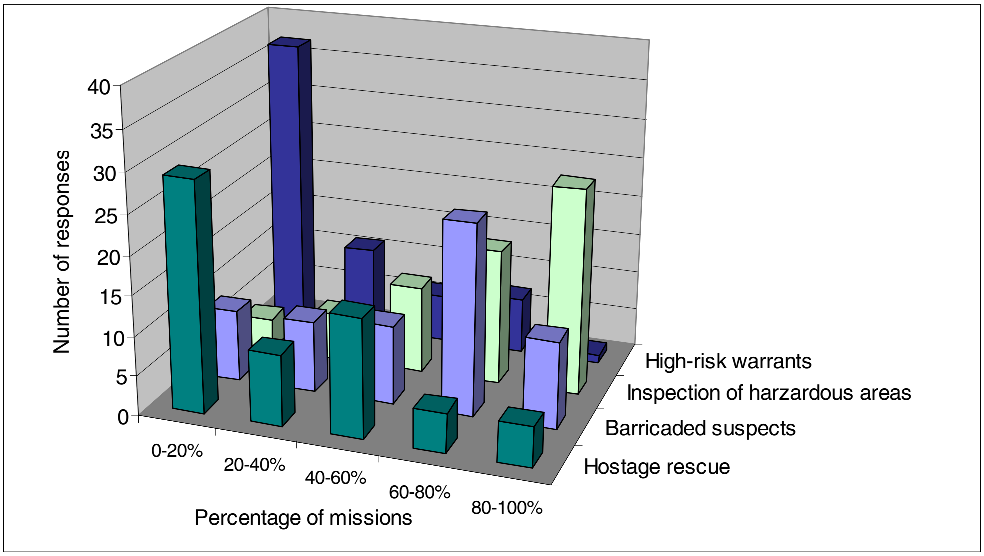

Figure 4. Frequency of robot use (if available) in various scenarios.

2.2.4 Tasks

Two questions were posed regarding the importance of various tasks a robot could be asked to perform. The first question queried the percentage of times a certain task is performed (by any method), and the second question determined the percentage of the times that the task is performed *when it would be performed by a robot, if available.* The role of the first question is to clarify the second question for the survey respondent. The importance of robots to the task is primarily determined by the answers to the second question. This is analogous to the importance of the accuracy of a firearm. It does not matter if firing a weapon only takes place during a miniscule percentage of the missions, the accuracy of the shots when they are fired is still very important. Figures 5 to 13 summarize the results, with the percentage of times a task would be performed during the above missions listed on the horizontal axis. The vertical axis represents the number of responses.

We can see from these graphs that the tasks most demanded by respondents for robotics support are *delivery of small items* (wireless telephones, food, etc.) and *passive remote communication* (where the target person is not required to cooperate by using a telephone). These are followed *by video/audio surveillance* and *retrieval of small objects*.

Other tasks mentioned (by one respondent each) include:

- Creating a diversion
- Providing zone defenses, alerting units when suspects are moving
- Identification of subjects and weapons
- Valve manipulation
- Retrieving injured officer or hostage from hostile environment

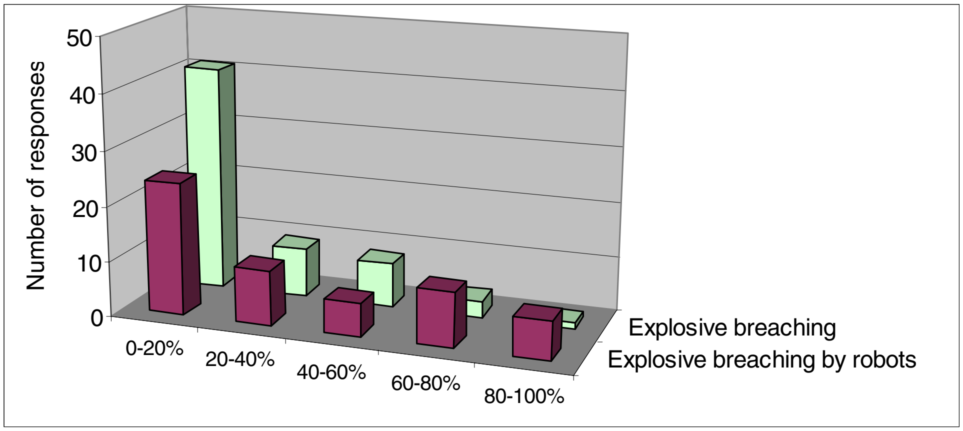

Figure 5. Explosive breaching.

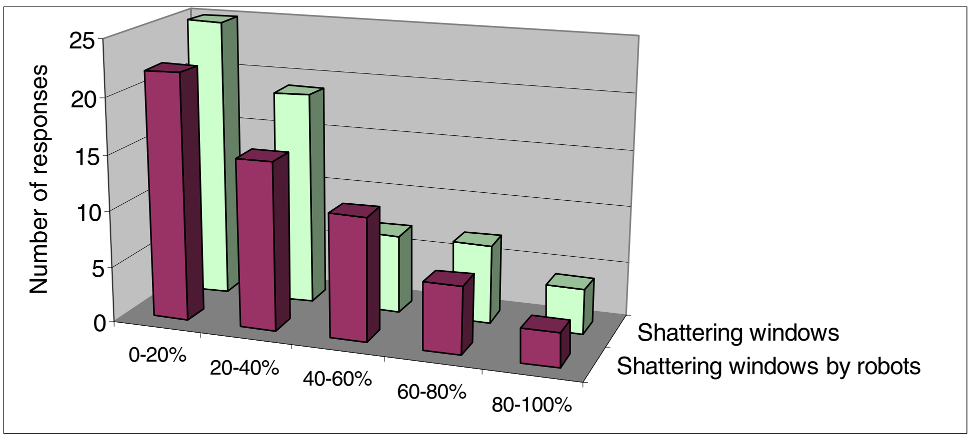

Figure 6. Shattering windows.

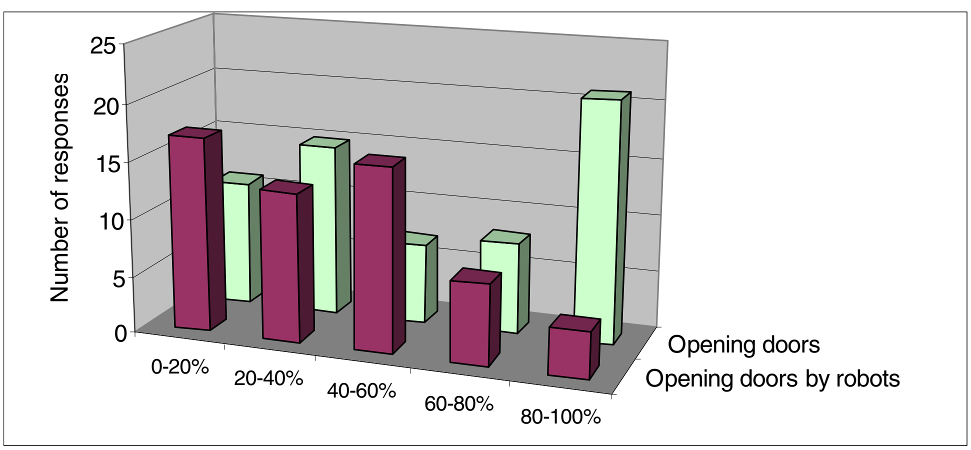

Figure 7. Opening doors.

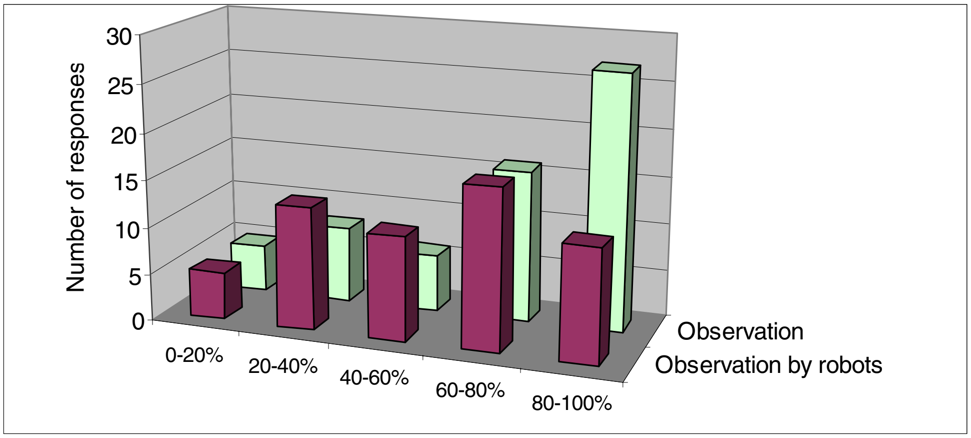

Figure 8. Observation/visual surveillance.

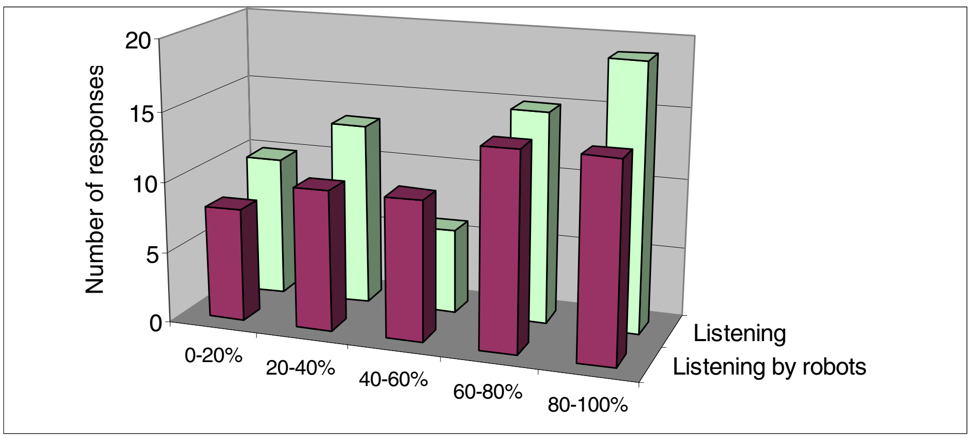

Figure 9. Listening/audio surveillance.

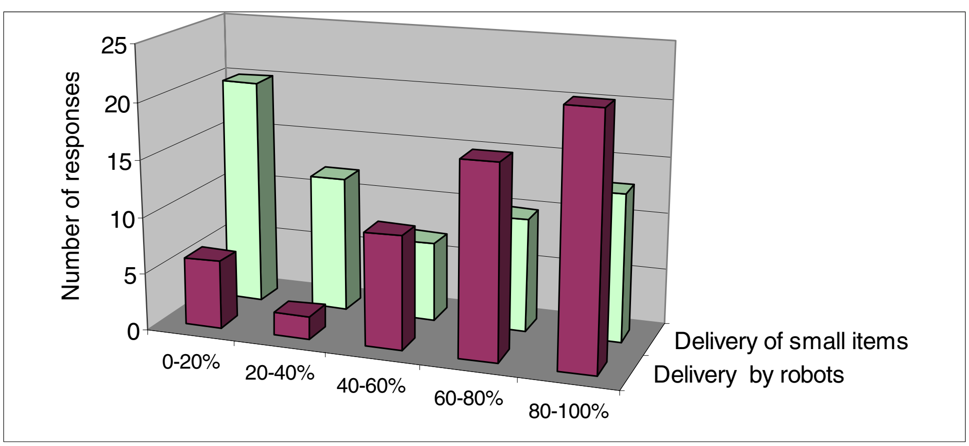

Figure 10. Delivery of small items.

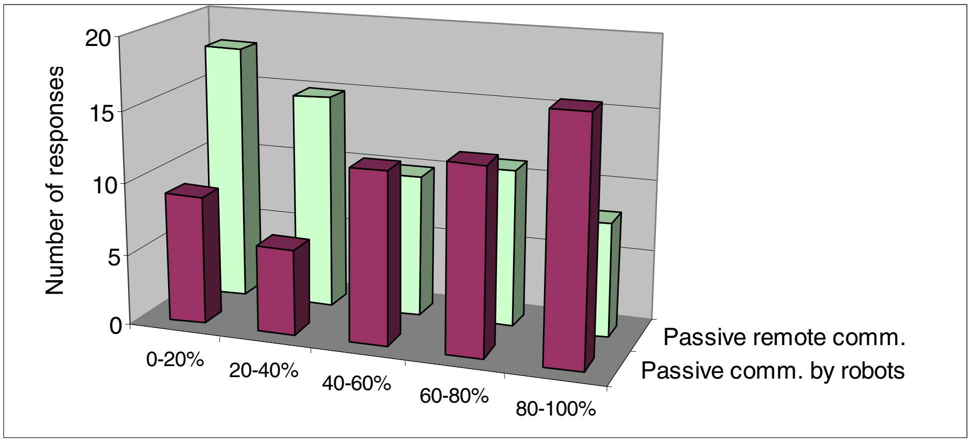

Figure 11. Passive remote communication (by speaker and microphone).

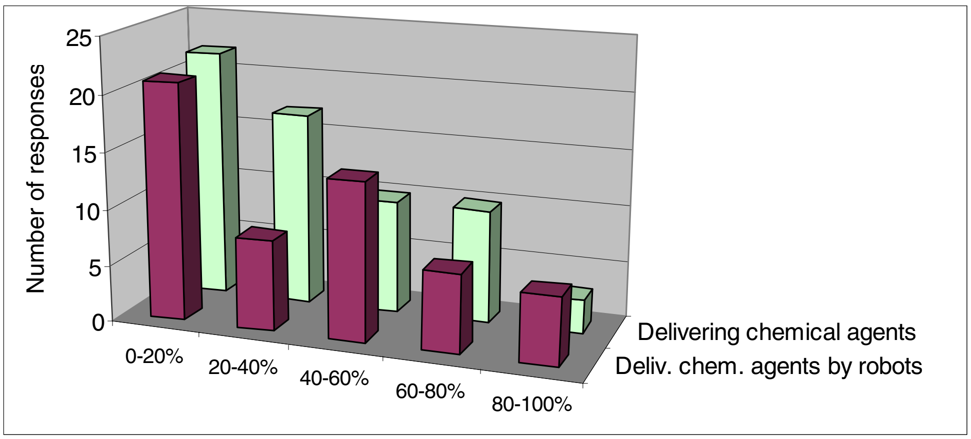

Figure 12. Delivering chemical agents.

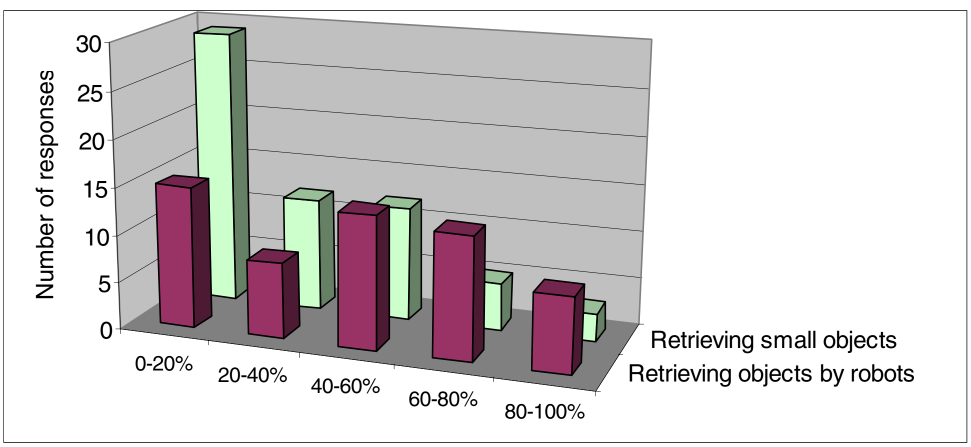

Figure 13. Retrieving small objects.

2.2.5 Tools

Figures 14 to 16 show the perceived usefulness of various robot-mounted tools. The frequency that each tool would be used, if available, is listed on the horizontal axis. The vertical axis represents the respondents' selections. The respondents placed emphasis on sensors and effectors, while robot-mounted weapons were not viewed as important. Types of less-lethal weapons mentioned include beanbag rounds, sage rounds, pepper spray, sting balls, nets, TASER and pulse lighting.

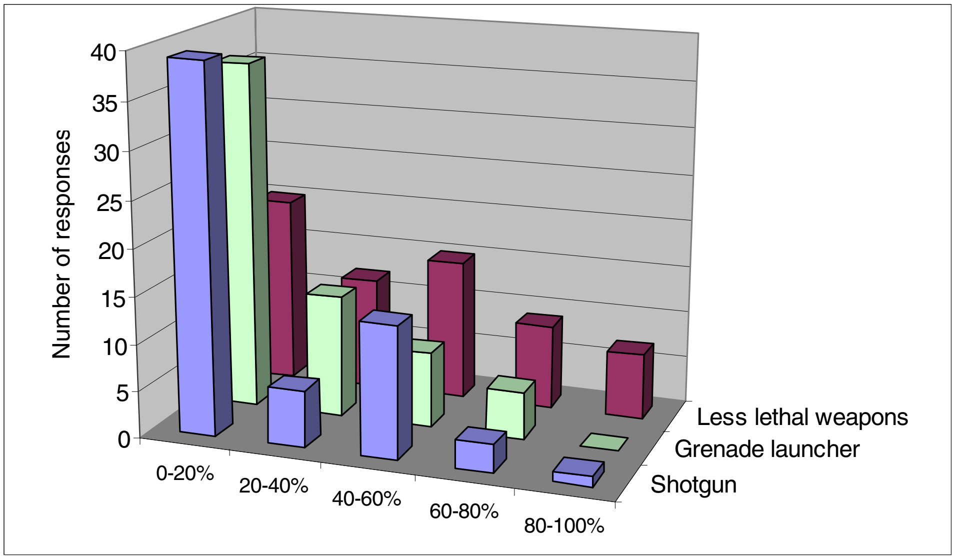

Figure 14. Robot-mounted weapons.

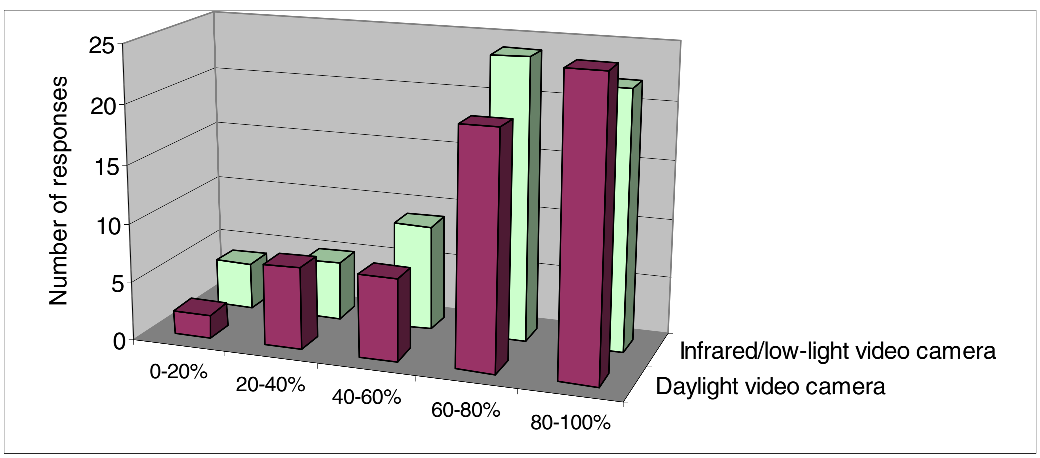

Figure 15. Video cameras.

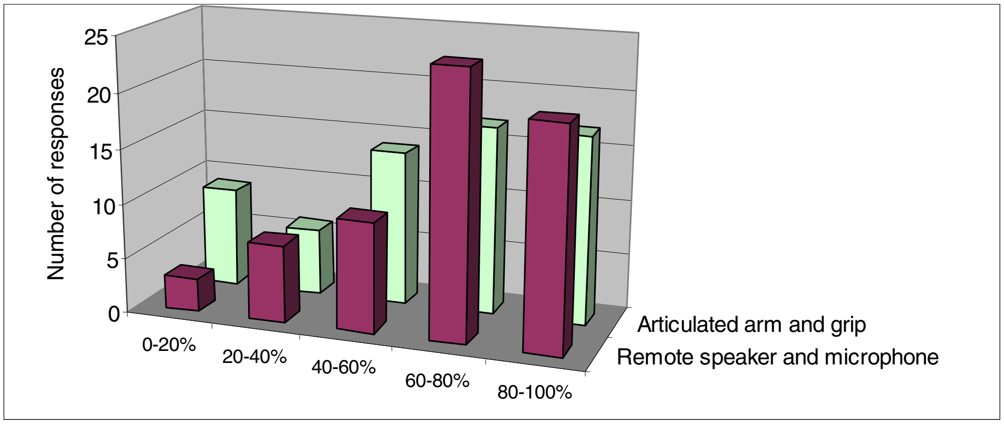

Figure 16. Other sensors and effectors.

One or more respondents also indicated that law-enforcement robots could use the following tools:

- Tire-deflating strips
- Chemical/biological agent sensors
- GPS/dead-reckoning locating
- Laser range finder
- Window punch for automobiles

2.2.6 Features

The next group of graphs summarizes the responses on the most reasonable or appropriate values for various features of a robot that would best meet the respondents' needs.

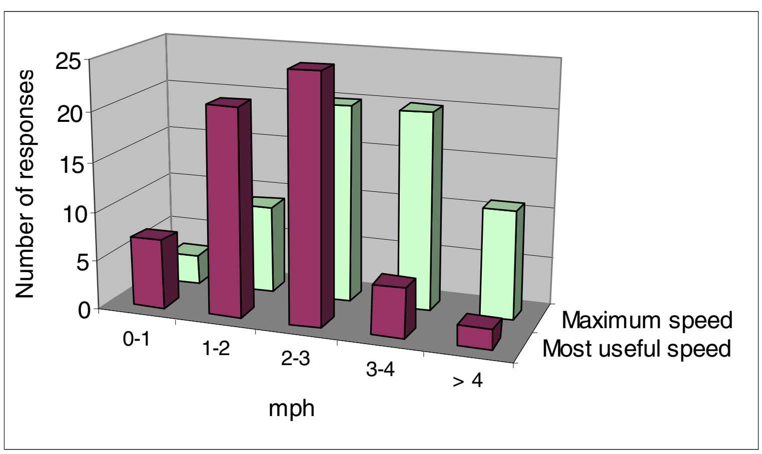

Figure 17. Maximum and most useful speeds.

While most respondents chose a maximum speed of 2 to 4 miles per hour, the most useful speed was pegged at around 2 miles per hour.

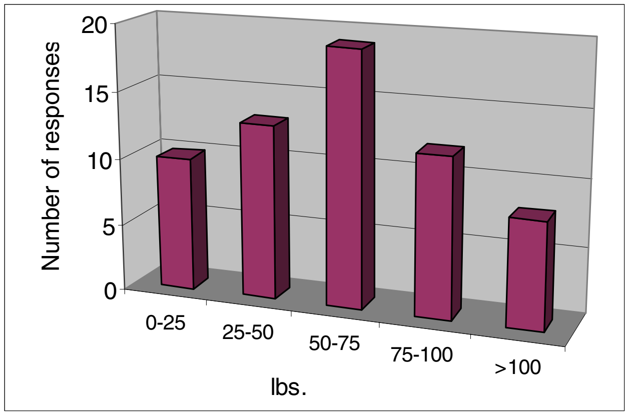

Figure 18. Most appropriate weight.

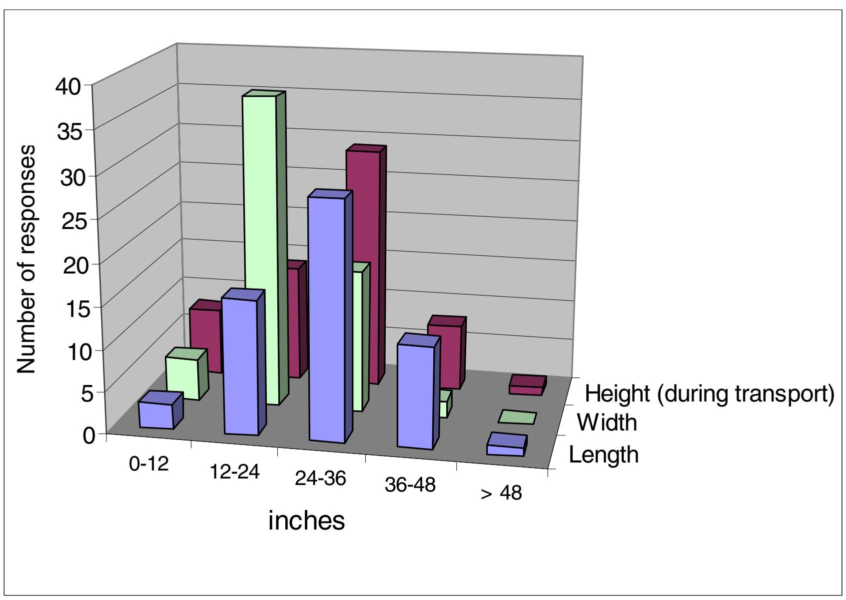

Figure 19. Most appropriate size.

The composite most appropriate size for the robot is a rectangular box, 24 to 36" long, 12 to 24" wide, 24 to 36" high (stowed), and weighing 50 to 75 pounds. There is demand for robots smaller than this, but almost no demand for robots larger than 4 feet on each side.

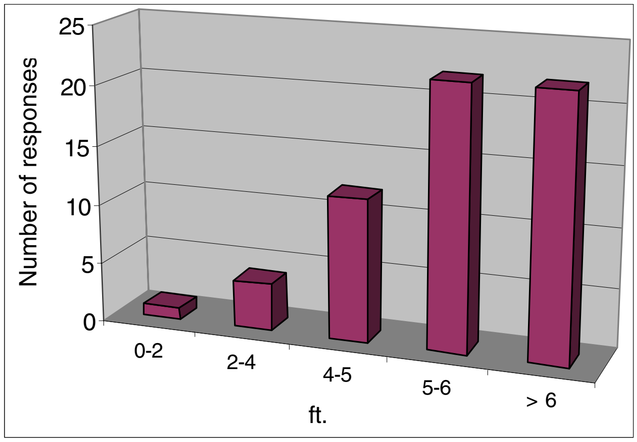

Figure 20. Maximum reach.

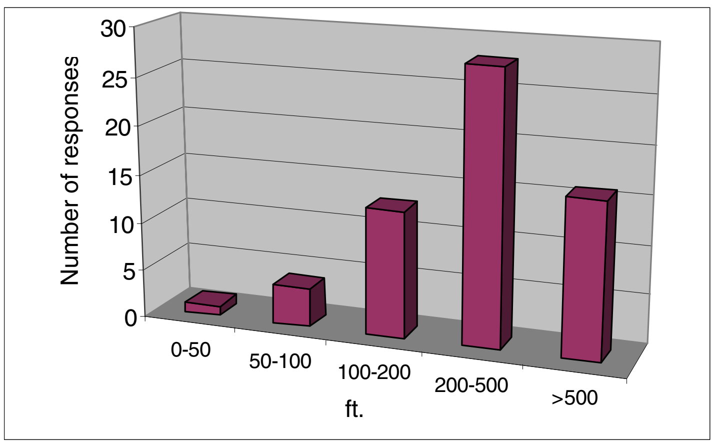

Figure 21. Operating/stand-off distance.

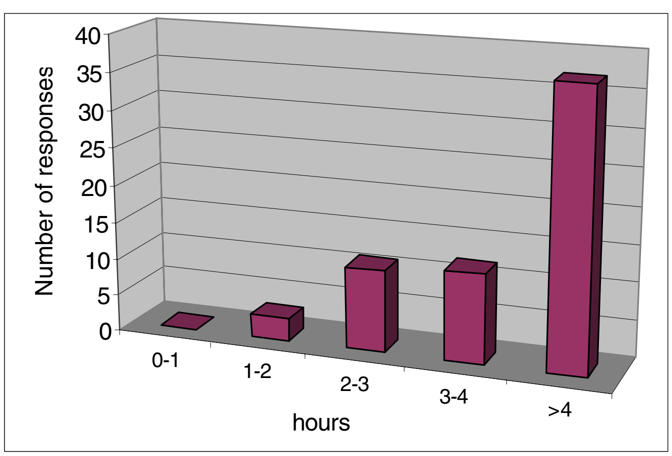

Figure 22. Mission duration.

The question on mission duration was not optimally designed. As a result, we know that the desired operational duration is over 4 hours, but we do not have an upper bound.

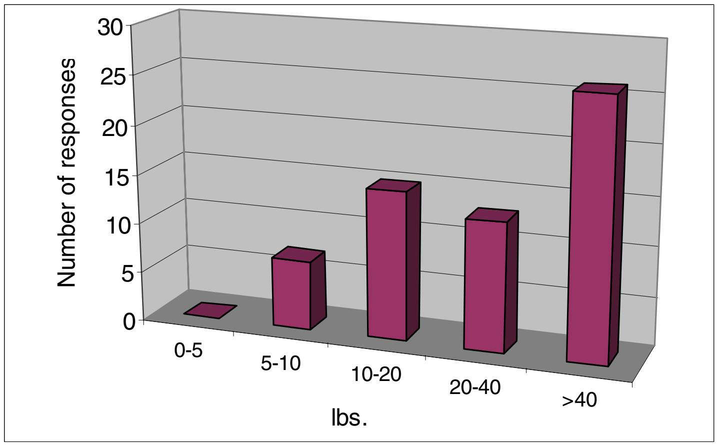

Figure 23. Manipulator lift capability.

The responses to this question were somewhat bimodal. There was desire for robots with maximum lift capability at around 20 pounds and at over 40 pounds.

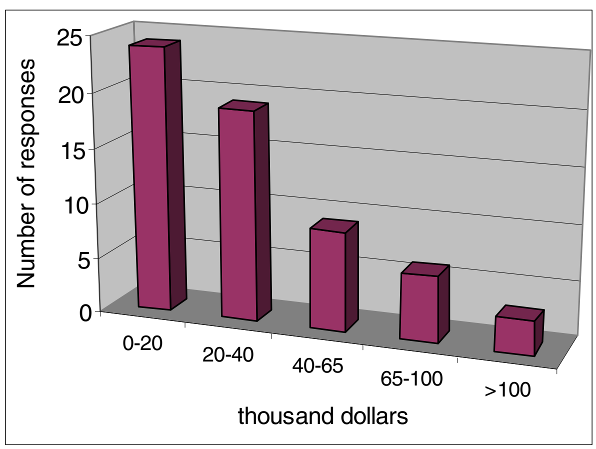

Figure 24. Reasonable procurement cost.

A clear majority of the responses picked a reasonable procurement cost of under $40K. This reflects the limited budgets faced by most local law-enforcement agencies, as singled-out separately by several survey participants.

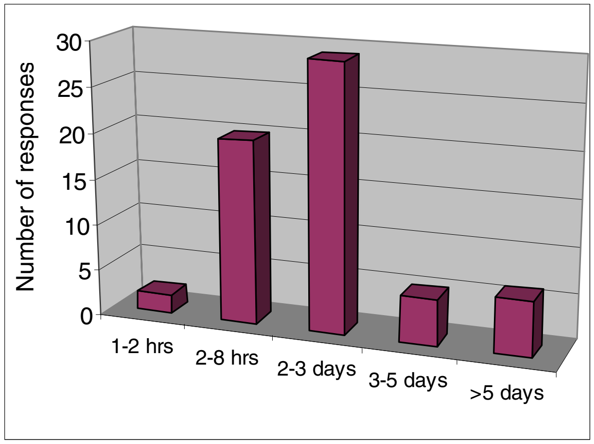

Figure 25. Reasonable initial training time.

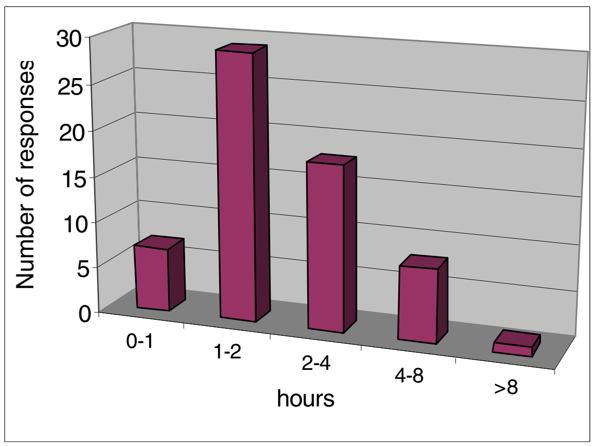

Figure 26. Reasonable maintenance time per month.

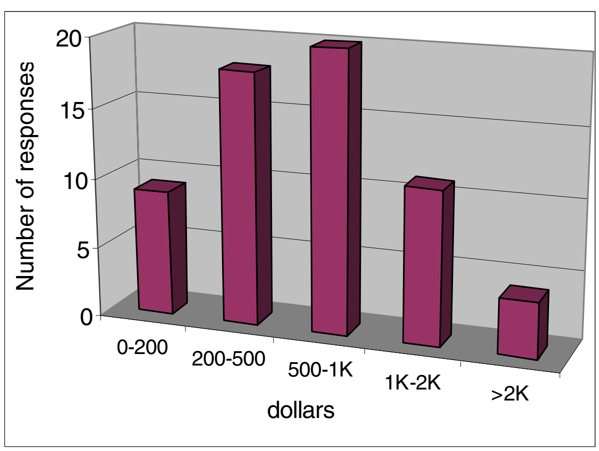

Figure 27. Reasonable annual maintenance cost, excluding in-house labor.

2.2.7 Mobility

Figure 28 summarizes the perceived importance of the robot being able to traverse certain outdoor terrain. On the horizontal axis, 4 is most important, 0 is least important. The number of responses is given on the vertical axis for each terrain. From this figure, we can see a heavy emphasis on being able to traverse over curbs, bumpy dirt, and high grass, followed by mud, snow, and rubble. Sand received the least emphasis.

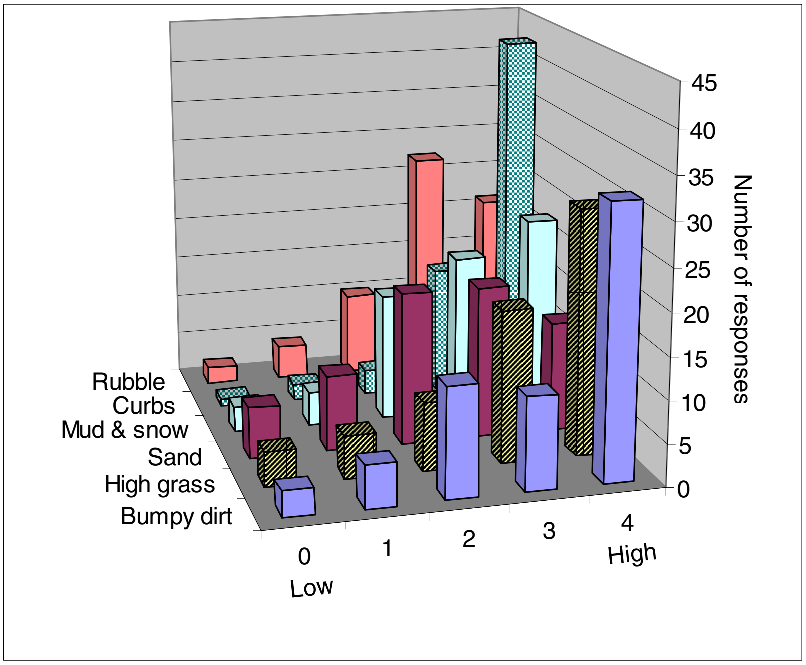

Figure 28. Importance of being able to traverse various outdoor terrain.

Figure 29 provides similar responses to various indoor terrain features. We see a unique emphasis on the ability to traverse stairs, followed by the capability of travelling over loose rugs and newspapers, and not getting entangled in telephone wires and cables. Though not as strong as the previously mentioned categories, the ability to go under crawlspaces was also considered important. One survey participant also added the capability to operate in an airplane or bus aisle.

2.2.8 General Features

Figure 30 shows the perceived importance of various remote control and communication links. A radio frequency (RF) link was considered most important, followed by a dual-RF/optical-fiber link, with optical fiber alone last.

Figure 31 confirms the importance of having a large viewing screen at the command post and a tactical handheld viewfinder that the robot operator can use either in full sunlight or inconspicuously in darkness.

Figure 32 shows the perceived importance of some self-defense mechanisms. An armored body and hidden deactivation switch were judged more critical than keep-away defensive mechanisms (tear gas, electric shocks, etc.), although all three were considered important.

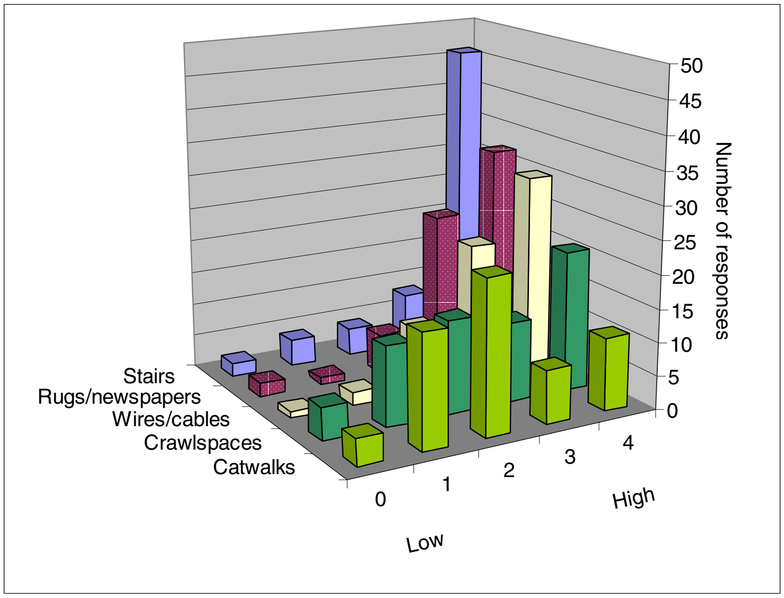

Figure 29. Importance of being able to traverse various indoor terrain features.

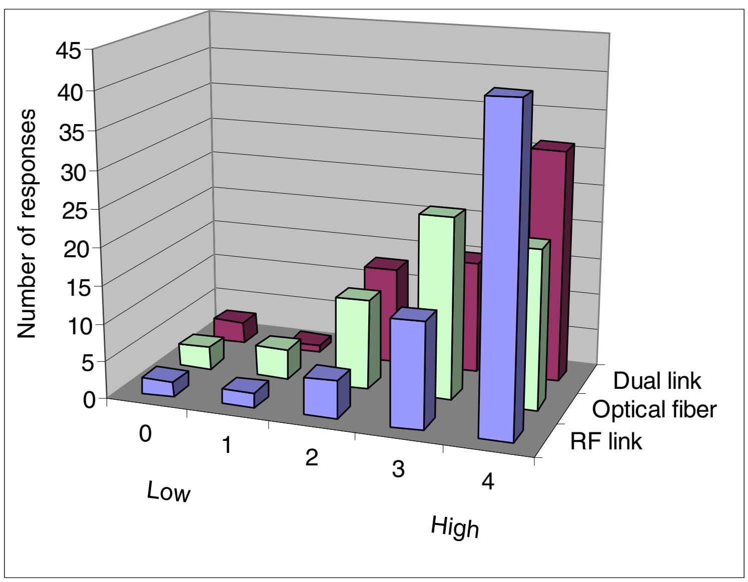

Figure 30. Importance of various communication links.

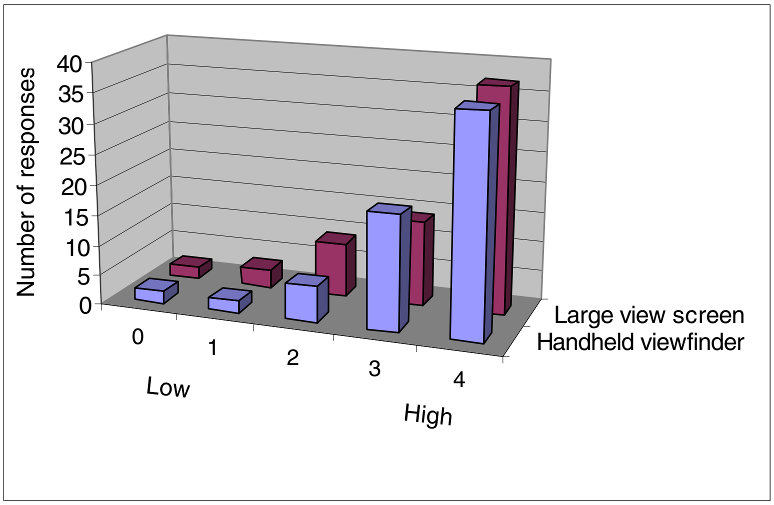

Figure 31. Importance of various video interfaces.

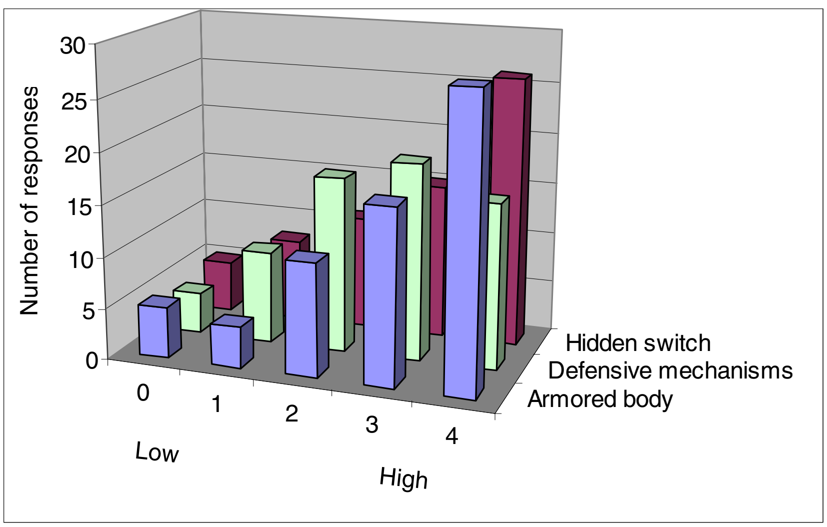

Figure 32. Importance of various self-defense mechanisms.

Figure 33 covers more advanced features. Self-righting topped the list, followed by back-packability and semi-autonomy. The ability to operate several robots concurrently did not receive many votes, although the few that voted for it mentioned possible use in scenarios involving large buildings, with one robot acting as a strategically placed sensor and another performing specific tasks.

The more obviously desirable features (weatherproof, ruggedness, modularity, and use of standard power sources) were endorsed by most respondents (figure 34).

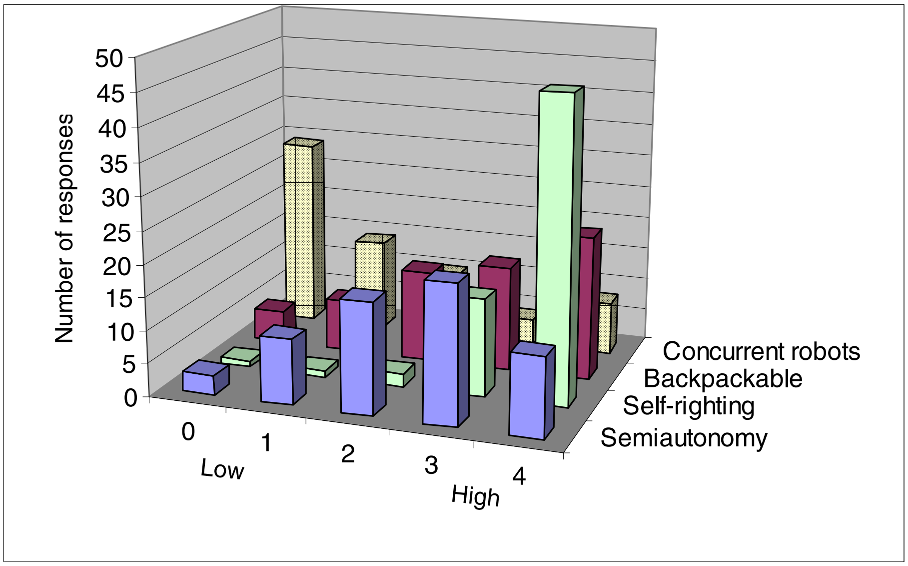

Figure 33. Importance of various advanced features.

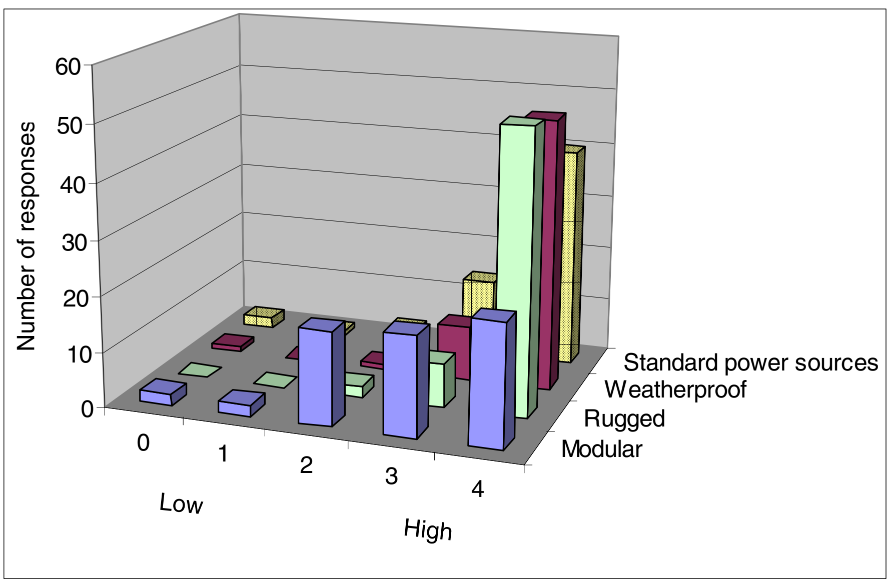

Figure 34. Importance of various standard features.

2.2.9 Past Experience

Our survey also asked law-enforcement personnel about their experience with the robots they currently use or have used in the past, and any improvement they feel is needed. On the brands of the robots used, two consistently came up: Remotec and Pedsco (although a few respondents could not recall the brand of the robot they used). Although the respondents indicated a success rate of between 50% and 95% using existing robots on non-EOD missions, some areas that could be improved based on their experience were as follows:

- Hard-line cable control link (an RF link is desired)
- Unreliable RF link
- Limited range, speed, and battery life
- Complicated controls
- Robot arm lacking adequate degrees-of-freedom
- Mobility over rough terrain (from users of smaller models)
- Lack of agility, difficult to control (from users of larger models)

2.2.10 General Interests

The last question we asked was designed to sense the level of interests among law-enforcement personnel in different types of mobile robots. Ground robots were indeed where the most interests lie, followed by a pocket-sized robot that can be thrown or launched through a window. There was little interest in air, underwater, or water-surface crafts (figure 35). A few respondents mentioned liability as the main reason for the low interests in unmanned air vehicles, especially in crowded urban areas.

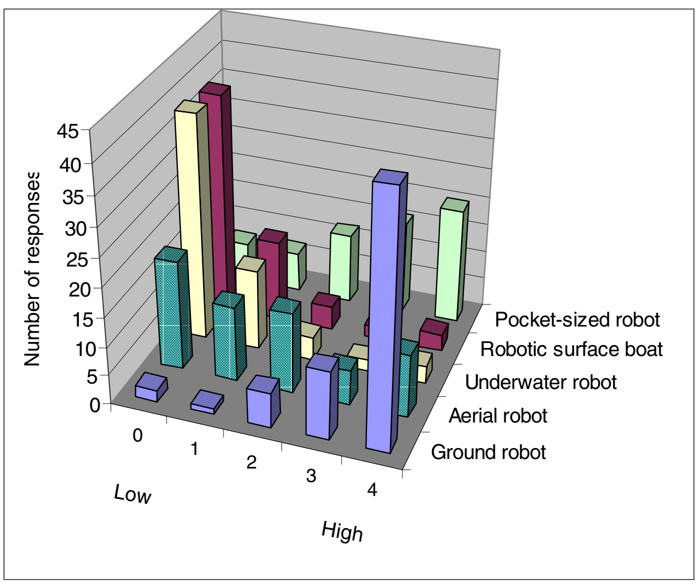

Figure 35. Law-enforcement interests in various types of mobile robots.

2.3 DIFFERENTIATION BY ROBOTICS EXPERIENCE

We also separated the data into two sets: one set composed of responses from people reporting no prior experience with robotics, and the second set all others. The tabulation program was run again on the two sets of data (see appendices C and D). We found no significant difference in most answers, except the group with robotics experience placed more importance (compared to figures 20, 21, and 23) on the following:

- Maximum reach for robot (much stronger response for “over 6 feet”)

- Longer stand-off distance ("over 500 feet" instead of "250 to 500 feet")
- Lift capability (much stronger response for "over 40 lbs.")

Appropriately, this group also were more inclined to accept a higher acquisition cost (20 to 40 thousand dollars versus under 20 thousand dollars—see figure 24).

On terrain features, the group with robotics experience placed more emphasis on being able to traverse sand and lower emphasis on traversing mud and snow (compare to figure 28).

Of the general features (figures 30 through 34), the experienced group placed lower importance on semi-autonomy, armor, self-defense and back-packability, and higher emphasis on modularity.

The answer concerning appropriate weight of the robot generated interesting results when differentiated. While the group with no experience overwhelmingly picked 50 to 75 pounds as most appropriate, the answers from the experienced group were bimodal. There were strong responses both at 25 to 50 pounds and 75 to 100 pounds. Perhaps this reflects the remark from several respondents with robotics background that the robotics needs of the law-enforcement community cannot be satisfied with just one general-purpose robot. There is a requirement for a heavy, large robot and a lighter, smaller, and more agile robot.

3. DEPARTMENT OF DEFENSE EFFORTS

While there are many commercial robots in existence that may satisfy some of the identified needs of the law-enforcement community, a survey of those robots is outside the scope of this report. Those interested in examining available commercial platforms are urged to consult sources such as the Unmanned Vehicles Handbook (reference 8) and our Small Robot Technology Database (reference 9). Here, we discuss only unclassified robotics research and development (R&D) programs by various segments of the Department of Defense, focusing on ground robots.

3.1 JOINT ROBOTICS PROGRAM (JRP)

To reduce duplicated ground robotics R&D efforts among various branches of the Department of Defense, Congress created the Joint Robotics Program (JRP) under the Office of the Secretary of Defense in 1989 (reference 10). JRP oversees all funding and technology priorities for these efforts while the services and defense agencies' program offices continue to conduct the daily management of these programs. JRP projects range from the more mature EOD systems and vehicle teleoperation kits to advanced software architectures and robotic technology demonstrations (reference 11). The majority of the ground robotics programs are currently managed by the Unmanned Ground Vehicles/Systems Joint Project Office (UGV/S JPO), a joint Army and Marine Corps organization (reference 12).

3.2 UGV/S JPO

All JRP robotics developments of interest to the law-enforcement community currently fall under the management of the UGV/S JPO. They are summarized below.

3.2.1 Man-Portable Robotic System (MPRS)

The Man-Portable Robotic System (MPRS), nicknamed URBOT (for urban robot), is a small surveillance robot under development at SSC San Diego (references 13 and 14). The goal of the program is to develop economical, rugged, and lightweight mobile robots for surveillance operation in urban environments. This program bridged the gap between users and technologists by developing prototypes that were field tested by the end-users (soldiers). The first-generation prototype was based on a modified Lemming platform from Foster–Miller (Waltham, MA). The second-generation prototypes, of which four were produced, were based on the Foster–Miller Tactical Adjustable Robot. The robot weighs 65 pounds and is approximately 36 inches x 24 inches x 12 inches in size (see figure 36). MPRS contributed several significant features and developed the following important design rules that might be applicable to law-enforcement robots:

1. An optimized sensor package was developed based on user feedback, including a forward-looking video camera, lights, and a microphone. The package was mounted in a watertight Sensor Snout that can be tilted up or down 90 degrees to allow observation of obstacles while breaching obstructions.

2. A driving camera was added on the top of the robot, towards the back of the platform, to improve orientation during driving. This feature allowed a forward field-of-view that included the left and right drive tracks.

3. Instead of self-righting, URBOT is fully invertible (i.e., it can be operated either upside down or rightside up with no preference). An identical driving camera was mounted on the bottom

of the robot to be used when the robot was operating upside down, and the video output from the surveillance camera was invertible.

4. Semi-autonomy was found to be inappropriate. During operation in hostile environments, the robot must move slowly and stop often, allowing the operator to closely examine the video for anything of tactical importance. Thus, a purely teleoperated control strategy was requested by the users, and the more intelligent “reflexive teleoperation” feature was removed from the second-generation robots. Furthermore, the default drive mode was set to “all stop” (i.e., the robot stopped when all drive-control buttons on the control pendent were released).

5. A rear-looking video camera with infrared (IR) capability (eliminating the need for backup lights) was added for backing up the robot from tight spots and tunnels.

6. To satisfy the users’ request for a tighter turning radius, the center sprocket on each side was increased in diameter from 10 to 11 inches, providing a “high-center” effect. This feature also improved maneuverability on most surfaces, including indoor carpet.

7. A high-speed digital RF video link capable of providing real-time video (15 to 20 frames per second) was implemented. This feature eliminated ghosting and dropouts associated with an analog link, and consumed much less power. The digital video/audio system was also capable of providing bidirectional audio between the controller and the robot, allowing two-way verbal communication with a remote hostile element.

8. The surveillance camera was equipped with 24X zoom, autofocus, and auto-iris functions that can also be controlled by computer (i.e., manually), allowing close-up inspection of targets and optically isolating trip wires and other small objects. The camera also had electronic image stabilization, eliminating frame-to-frame jitter caused by mechanical vibration during driving.

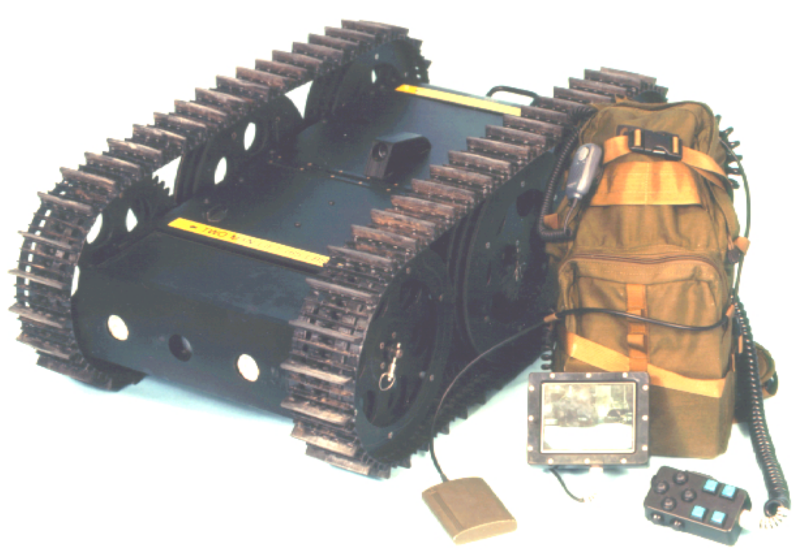

Figure 36. URBOT (MPRS) with operator control equipment.

3.2.2 SPIKE

The Army Infantry Center at Fort Benning, GA, has evaluated the SPIKE vehicle (produced by II-Tracker, Portland, OR) for use as a reconnaissance and breaching vehicle for Military Operations in Urban Terrain (MOUT). The SPIKE vehicle can be thought of as a miniature tank (425 pounds, 38 inches x 28.5 inches x 22.5 inches; see figure 37). It has a radio control link with a quarter-mile range, and an 8-hp diesel engine that can take the vehicle up to 15 mph.[1] An attractive feature of the SPIKE robot is its ability to breach doors simply by driving through them. Breaching of hollow-core and solid-core doors, and firing Stingmore mines (Claymore-like mines loaded with hundreds of rubber balls) from the SPIKE vehicle have been successfully conducted at Fort Benning.[2] It is also intimidating enough to potentially be used as a psychological weapon in some situations. (From our conversations with law-enforcement officers, we discovered two seldom-mentioned uses for robots: as a psychological weapon, and to limit liability by showing that positive steps have been taken to ensure public and officer safety.)

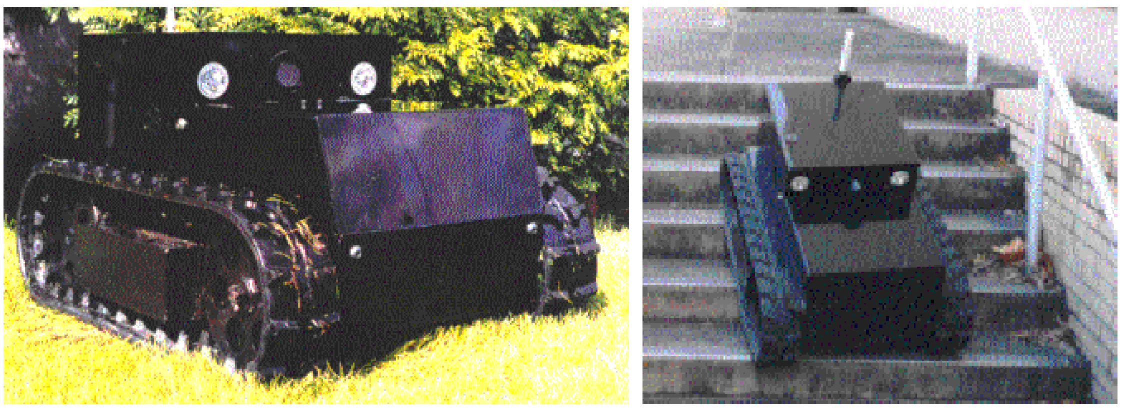

Figure 37. SPIKE robot.

[1] Telephone and electronic correspondence with Mr. George Osgood, II-Tracker, Portland, OR, 8 August 2000.

[2] Telephone interview with Mr. Irving Rodriguez, Directorate of Combat Development, U.S. Army Infantry Center, Fort Benning, GA, 21 August 2000.

3.2.3 MATILDA

The MATILDA is a low-cost (under $25,000 base price) reconnaissance robot built by Mesa Associates (Madison, AL). It weighs 40 pounds and measures 26 inches long x 20 inches wide x 12 inches high (platform only). Optional attachments include a small trailer (400-pound capacity), a manipulator arm, and a remotely detachable breaching mechanism that allows explosive charges to be attached to a door or wall (see figure 38). UGV/S JPO funded the upgrade of the basic unit (Point Man) to the Urban Warrior version, and acquired 10 units. The National Guard's Civil Support Detachment/Weapons of Mass Destruction Teams (CSD-WMD) are evaluating four of those units).[3, 4] Personnel from the Army Maneuver Support Center (Fort Leonard Wood, MO) conducted tests of explosive breaching on simulated walls and doors using the MALTILDA robot at the MOUT Advanced Concept Technology Demonstration (ACTD) in Fort Benning, GA, during Summer 1999.[5]

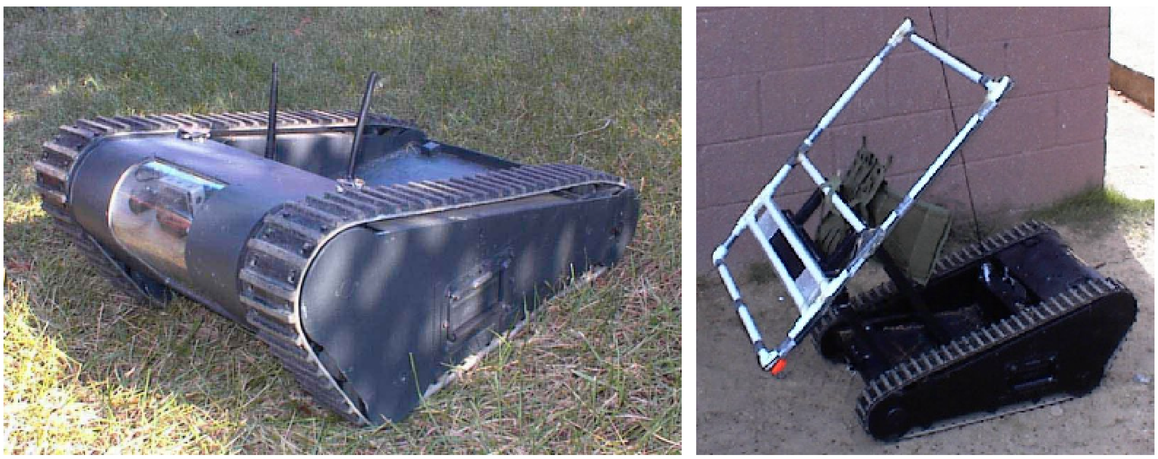

Figure 38. MATILDA robot (left) and MATILDA with breaching mechanism (right).

---

[3] Interview and follow-up electronic correspondence with Mr. Keith Anderson, UGV/S JPO, Huntsville, AL, 1 June–16 August 2000.

[4] Telephone and electronic correspondence with Mr. Don Jones, Mesa Associates, Madison, AL, 10 August 2000.

[5] Telephone interview with Sgt. Bill Rodstad, Department of Training and Development, U.S. Army Maneuver Support Center, Fort Leonard Wood, MO, 21 August 2000.

3.2.4 Other Robot-Mounted Weapons and Tools

The UGV/S JPO tested several robot-mounted less-lethal weapons. In 1999, JPO demonstrated to the U.S. Marine Corps a Foster–Miller device mounted on a SARGE vehicle (figure 39) that can be loaded with numerous non-lethal weapon canisters such as rubber balls, bean bags, nets, etc.[3, 6] (SARGE is a reconnaissance robot originally designed by Sandia National Laboratories and currently produced by SUMMA Technology of Huntsville, AL.) A similar but smaller version of this less-lethal weapon launcher is available for smaller robots such as the Foster–Miller Lemming (see figure 41).

The Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) has also developed a water cannon that can shoot water and other non-conventional munitions at high velocity. Although its primary use is in EOD applications, the water cannon was successfully test fired from the Mini-Flail (a 2400-pound mine-clearing robot built from a John Deere Skip Loader chassis—see figure 40) in breaching exercises at Ft. Leonard Wood in 1999. Water and steel balls were shot against wood and cinderblock walls.[7] Because of the strong recoil, this device can only be operated from heavier robots.

Figure 39. SARGE robot with Foster–Miller less-lethal weapon launcher.

---

[6] Telephone and electronic correspondence with Mr. Arnis Mangolds, Foster–Miller Inc., Waltham, MA, 17–18 August 2000.

[7] Telephone interview with Mr. Earl Scroggins, Naval Explosive Ordnance Disposal Technology Division, Indian Head, MD, August 24, 2000.

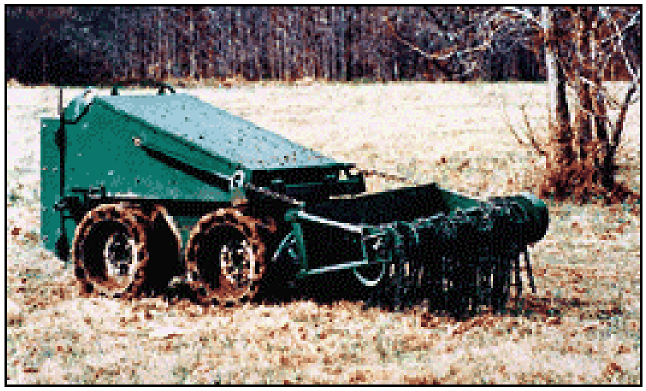

Figure 40. Mini-Flail.

3.3 DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

Robotics efforts of the Defense Advanced Research Projects Agency (DARPA) operate outside (but in cooperation with) JRP. Most DARPA robotics projects involve advanced technology contributing to robotic autonomy or intelligent cooperation between robots. These are currently of low interest to the law-enforcement community, which favors low cost and simple teleoperation. (Among respondents with robotics background, the importance of semi-autonomy rated a 2 on a scale of 0 to 4.) However, some DARPA projects have explored technology areas that may benefit law-enforcement robotics efforts.

3.3.1 Tactical Mobile Robotics (TMR)

DARPA's Tactical Mobile Robotics (TMR) program aims to develop new technologies to address some of the most technically challenging aspects of operations in complex terrain (references 15 and 16). This project originated from conceptual requirement analyses done by the Special Operations Forces (reference 17). Although TMR's focus is on small, semi-autonomous robots, some autonomous/semi-autonomous functions being explored are important to all mobile robots operating in hostile environments. These functions include the following:

- Self-righting (demonstrated with IS Robotics' Urban Robot)
- Recovery from lost contact or control (by retracing path)

TMR also funded Foster–Miller to develop and demonstrate several robotic mission packages. The following items have been demonstrated on a Lemming base[6, 8]:

- Launch of snare nets, tear gas, rubber balls and other less-lethal munitions (see figure 41)
- High-voltage discharge for anti-handling and self-protection
- Non-explosive breaching using a circular saw device (see figure 41)

---

[8] Interview with Dr. Douglas Gage, SSC San Diego (now with DARPA ITO), 2 May and 21 August 2000.

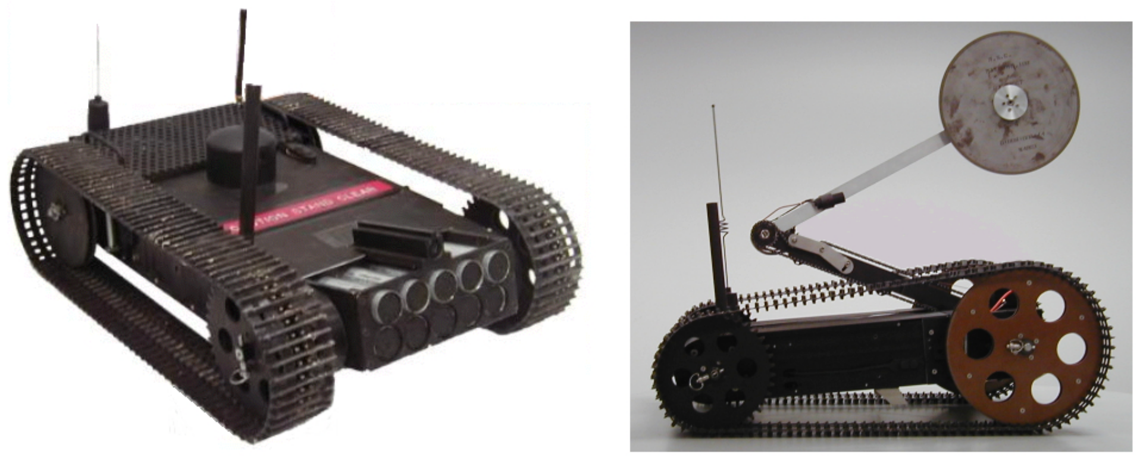

Figure 41. Lemming robot with less-lethal weapon launcher (left) and breaching saw (right).

Another element of the TMR program looks at small robots that can be launched from a larger robot or thrown by a human operator (Throwbot class). This type of robot received the second most interest, after conventional ground robots, from the law-enforcement personnel surveyed. TMR funded the Charles Stark Draper Laboratory (Cambridge, MA) to developed several prototypes, and has also explored Throwbot concepts using the SuBot (Small Unit Robot—figure 42), developed with internal funding by the Science Applications International Corporation (Englewood, CO) (reference 18). SuBot is approximately spherical in form, with a 16-cm diameter. It has two-wheel skid steering with a tail stabilizer. Electronics include a video camera, RF receiver, and video transmitter with a 30-m range.

Figure 42. SAIC's SuBot.

3.3.2 Distributed Robotics (DR)

DARPA's Distributed Robotics (DR) program focuses on advanced technologies supporting large systems of mini and micro robots. However, one project funded under this program, managed by the Center for Distributed Robotics at the University of Minnesota, has potential for applications in law enforcement in the very near future. This project involves small marsupial robots (Ranger) that can carry and launch up to 10 even smaller robots (Scout) (reference 19). The Scout vehicles are cylindrical, 40 mm in diameter and 110 mm long (see figure 43). They can roll up 20-degree slopes, and hop over 4-inch obstacles (by winding and releasing a leaf-spring tail). The Scout sensor suite, depending on applications, may include a video camera (fixed or mounted on a retractable pan-and-tilt unit), microphone, vibration sensor, gas sensor, and other sensors. It has a short-range analog RF link, and can be launched through windows, either by the launcher on the Ranger or by a grenade launcher. The robot fits snugly inside a protective covering called a Sabot that absorbs much of the impact during the launch.

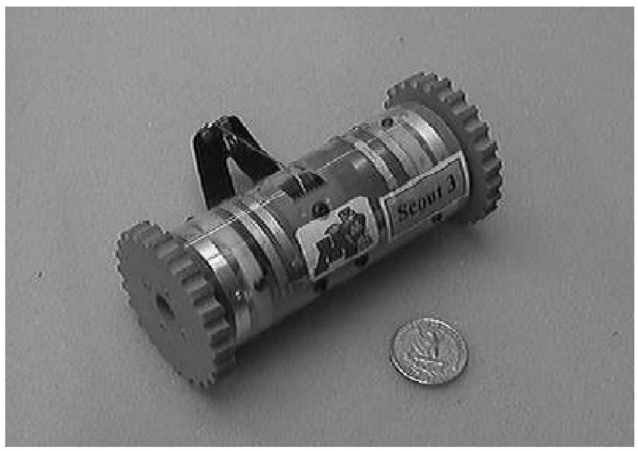

Figure 43. Scout robot.

3.3.3 Micro Unattended Mobility System (MUMS II)

Somewhat related to the pocket-sized robot concept, DARPA is funding IS Robotics (Somerville, MA) and Sandia National Laboratories (Albuquerque, NM) to develop a tactical sensor system that can be delivered by a grenade launcher. Named the Micro Unattended Mobility System (MUMS II), the sensor payload will be deployed using a standard M-203 grenade launcher (reference 20). To commence operation, the payload is aimed at a target zone on an outside wall between 10 to 50 inches above a window. Upon impact, as the shock-absorbing material is collapsing, an explosive nail is driven into the wall to attach the payload package. This attachment method was demonstrated on many wall surfaces, including reinforced concrete, concrete block, and wood frame. After attachment, the sensor system separates from the main package and drops down on a flexible arm until the window is in view. The operator remotely controls the arm to place a miniature camera up against the window glass (to minimize reflections and distortion). The operator would then be able to conduct visual surveillance of the room interior remotely through an RF link.

Although only in the initial design phase, MUMS II has good potential for use in tactical law-enforcement operations and should be followed closely.

4. CORRELATION BETWEEN LAW-ENFORCEMENT NEEDS AND DoD EFFORTS

Table 1 is a matrix matching robotic tasks and features against DoD efforts. The tasks and features selected are those considered most important or uniquely requested by the law-enforcement personnel surveyed.

From the survey, we saw that the law-enforcement community places the most emphasis on having robots perform the functions of: (1) small-item delivery, (2) passive remote communication, and (3) remote surveillance.

Small-item delivery is typically accomplished by robots with manipulators. Most teleoperated mobile robots are available with a built-in or optional manipulator. Thus, the selection criteria are the number of degrees-of-freedom of the manipulator, the ease of control, and the mobility of the platform.

Passive remote communication (i.e., communication requiring no button or switch activation on the remote end) has traditionally been accomplished with analog radios. With the advent of digital CODECs (coder/decoder) implementing the H.32X teleconferencing standards, much more robust communication (video and audio) is now available through digital links.

Table 1. Correlation between law-enforcement needs and DoD efforts.

	DoD programs and/or products under evaluation							
LE Needs	JPO/ MPRS	JPO/ SPIKE	JPO/ MATILDA	JPO/ Foster-Miller	NAVEOD-TECHDIV	DARPA/ TMR	DARPA/ DR	DARPA/ MUMS II
Tasks								
Surveillance	X	X	X			X	X	X
Delivery of items	Commercially available technology							
Passive communications	Commercially available technology							
Tunnel reconnaissance	X							
Features								
Stair climbing						X		
Robust RF link	X					X		
Longer battery life	Current research area, not specific to robotics							
Low cost			X					
Less-lethal weapons		X		X	X	X		
Robot Types								
Large robots		X						
Small robots	X		X			X	X	
Pocket-sized robot						X	X	X

Remote surveillance is an active technology development area where DoD has much to offer. Projects to watch for contributions in this area include JPO's MPRS and DARPA's TMR and MUMS.

The capability for reconnaissance of tunnels and storm drains at U.S. ports of entry was requested by a member of the Border Patrol. This application is being specifically addressed by the MPRS program and should be directly transferable.

On the issue of robot mobility, the ability to traverse rubble and stairs was considered most important, as was self-righting capability. The MPRS program (near-term) and the TMR program (long-term) are addressing these capabilities.

Law-enforcement personnel with robotics experience disliked hard-line control links and unreliable RF links. While the MPRS and TMR programs are addressing this issue with more reliable digital RF links and relays, continuous high-bandwidth non-line-of-sight communication is a significant problem that still needs a solution (reference 16).

Similarly, extending mission duration (through improved energy sources) was noted as a primary concern. Current research programs (not related to robotics) sponsored by DARPA and other agencies are addressing this issue.

Cost is often a major consideration with law-enforcement agencies. The low-cost MATILDA robots were developed to address this issue and are being evaluated by JPO.

Robot-mounted less-lethal weapons were not ranked high on the priority list, but are included here because this is an active topic in DoD robotics. JPO and the U.S. Army investigated several less-lethal weapon launchers, and DARPA funded Foster–Miller's development of several mission packages including less-lethal weapons.

From the survey results and discussions with law-enforcement personnel, it became evident to us that there will be no single robot that will meet all the demands of law enforcement beyond EOD. For example, a fairly large robot would be required to traverse rubble and other rough terrain, be able to handle a heavy payload, and act as a psychological weapon. The SPIKE vehicle, currently under evaluation by the Army, or one of the larger models of existing EOD robots, may be able to assume this role. However, a smaller robot that is more agile and can be more easily maneuvered in tight spaces for surveillance and remote communication purposes is also needed. The TMR and MPRS programs are looking at this type of application. On an even smaller scale, DARPA's TMR, DR, and MUMS programs are investigating pocket-sized robots that can be thrown, launched by a grenade launcher, or carried by another robot. This type of robot has also received interest from the law-enforcement community.

While we have included in this report DoD programs that could contribute to law-enforcement robotics needs beyond EOD, a complete survey of all robotics-related technologies must include ongoing university research and commercial developments and products. Assimilating these data in a meaningful fashion represents an enormous challenge because of the broad spectrum of disciplines supporting robotics and the explosive growth within many of these areas. Fortunately, a technology assessment of this type has already been started. JRP recently tasked SSC San Diego to develop and maintain a comprehensive Mobile Robot Technology Database, which will be available for access by all government agencies. This database will expand upon the currently available Small Robot Technology Database (reference 9) and will include platforms of all sizes and associated supporting technologies.

5. RECOMMENDATION

We have conducted a survey that identified the general robotics needs of the law-enforcement community. This, together with our survey of DoD robotics efforts and the upcoming availability of the Mobile Robot Technology Database, should provide a starting point for a Department of Justice (DoJ) program for the development of law-enforcement robotics beyond EOD. Because we have concluded that no single robot will satisfy the full spectrum of desired functionality, and it is too cost-prohibitive to develop many application-specific robots, we recommend that DoJ pursue the development of two classes of robot, separated by size. Each robot should be modular, with application-specific mission packages or tool sets that can be tailored to the needs of a specific user.

The most important criterion for a successful program is producing an end product that the user will use and appreciate. Closing the loop with the user should, therefore, be the number one priority throughout the design and development process. This task is often complicated by three factors: (1) the developing engineers typically do not know much about what the user does, (2) the users do not know much about what the technology can and cannot do, and so (3) the users do not know what to ask for in realistic functional capabilities. This report is an initial attempt at bridging this gap. However, several more iterations of information exchange between the users and the developers are needed during the execution of a successful acquisition program. We therefore suggest that the development of each of the suggested robot classes follow a user-centric, phased, rapid-prototyping approach that has resulted in the successful MDARS[9] and MPRS (reference 14) robotics development programs at SSC San Diego. This procedure involves the following:

- Interviewing the intended user face-to-face for specific applications where requirements are further quantified.
- Translating these requirements into needed system functionalities.
- Matching these functionalities to technological needs required to achieve successful implementation.
- Breaking these technological needs down into three categories:
    1. Those that currently exist as state of the art.
    2. Those that are likely to come along within the development schedule.
    3. Those that are project specific, unlikely to be addressed by industry or academia, and therefore must be developed as part of the program.
- Preparing a preliminary specification for a baseline configuration and presenting to the appropriate users for feedback.

---

[9] H. R. Everett et al. 1996. "Technical Development Strategy for the Mobile Detection Assessment Response System—Interior (MDARS-I)," Technical Note 1776. Naval Command, Control and Ocean Surveillance Center RDT&E Division (now SSC San Diego), San Diego, CA.

- Proposing a first-generation prototype design to the users for further feedback.
- Prototyping a revised design, then giving the prototyped unit to the users for extensive hands-on evaluation.
- Implementing a final design based on subsequent lessons learned in the real world.

To keep cost to a minimum, any design should leverage existing robotic platforms and other ongoing robotics projects. It should also be modular, with an eye towards simple expansion to include additional capabilities later. For fairly simplistic initial applications, an organization experienced in robotics development should accomplish the entire process in 12 to 14 months.

Finally, since law-enforcement and military applications often overlap, we recommend that DoJ personnel continue to maintain close liaison with DARPA and JRP, track current and upcoming DoD programs (such as the Joint DARPA/Army Future Combat Systems), and obtain input from JRP in the technology assessment, source selection, and development of robotics assets.

6. REFERENCES

1. Battelle Memorial Institute. 1999. *Final Report on Law-Enforcement EOD Robot* (TSWG Task T-150B2). Columbus, OH.

2. Space and Naval Warfare Systems Center, San Diego. *Survey on Law-Enforcement Needs for Non-EOD Robots.* 2000. San Diego, CA. URL: http://www.spawar.navy.mil/robots/lesurvey/

3. National Law Enforcement and Corrections Technology Center links, URL: http://www.nlectc.org/links/lelinks.html.

4. Officer.com, URL: http://www.officer.com.

5. Washington D.C. Metropolitan Police Department law-enforcement links, URL: http://www.mpdc.org/English/About/LELinks.htm.

6. New York City Police Department links, URL: http://www.ci.nyc.ny.us/html/nypd/html/sites.html.

7. National Tactical Officers Association, URL: http://www.ntoa.org/

8. *Unmanned Vehicles Handbook.* 2000. The Shephard's Press. Burnham, Bucks, U.K.

9. *Small Robot Technology Database*, Space and Naval Warfare Systems Center, San Diego, URL: http://robot.spawar.navy.mil/mprs/Home.asp

10. Joint Robotics Program, Office of the Secretary of Defense. "JRP Program History," URL: http://www.jointrobotics.com/History/index.html

11. Joint Robotics Program, Office of the Secretary of Defense. "Joint Robotics Program Master Plan, FY2000," URL: http://www.jointrobotics.com/WebDocs/2000MasterPlan/JRP%20Master%20Plan%202000.pdf

12. Unmanned Ground Vehicles/Systems Joint Project Office (UGV/S JPO), Redstone Arsenal, Huntsville, AL, URL: http://www.redstone.army.mil/ugvsjpo/

13. Man-Portable Robotic System. URL: http://www.spawar.navy.mil/robots/land/mprs/mprs.html

14. R. T. Laird, M. H. Bruch, M. B. West, D. A. Ciccimaro, and H. R. Everett. 2000. "Issues in Vehicle Teleoperation for Tunnel and Sewer Reconnaissance," IEEE International Conference on Robotics and Automation (ICRA 2000), April 2000, San Francisco, CA, URL: http://www.spawar.navy.mil/robots/pubs/icra2000b.pdf

15. J. Blitch, LTC. 1999. "Tactical Mobile Robots for Complex Urban Environments," *Proceeding of SPIE Volume 3838: Conference on Mobile Robots XIV* (pp. 116–128), September 1999, Boston, MA.

16. E. Krotkov and J. Blitch 1999. "The Defense Advanced Research Projects Agency (DARPA) Tactical Mobile Robotics Program," *The International Journal of Robotics Research,* vol. 18, no. 7 (Jul).

17. J. G. Blitch, LTC, et al. 1998. "SOMROPE I: A Simulation Based Risk Analysis for Robot Assisted Special Reconnaissance*," Proceedings of International Association of Science and Technology for Development (IASTED) International Conference: Applied Modeling and Simulation* (pp. 285–290), August 1998, Honolulu, HI.

18. J. R. Spofford, J. Blitch, W. N. Klarquist, and R. R. Murphy. 2000. "Vision-guided Heterogeneous Mobile Robot Docking," *Proceedings SPIE Volume 3839: Sensor Fusion and Decentralized Control in Robotic Systems II* (pp. 112–121), September 1999, Boston, MA.

19. D. F. Hougen. 2000. "A Miniature Robotic System for Reconnaissance and Surveillance," IEEE International Conference on Robotics and Automation (pp. 501–507), April 2000, San Francisco, CA.

20. L. Sword. 2000. "Micro-Unattended Mobility System for Grenade Launcher Deployed Sensors (MUMS II)," *Proceedings SPIE Volume 4040:Unattended Ground Sensor Technologies and Applications II* (pp. 176–180), 24–28 April 2000, Orlando, FL.

APPENDIX A: SURVEY QUESTIONNAIRE

Systems Center San Diego

Survey

Law-Enforcement Needs for Non-EOD Robots

The Space and Naval Warfare Systems Center, San Diego, has been tasked by the National Institute of Justice to conduct a survey on robotics needs by the law-enforcement community for applications other than explosive ordnance disposal (EOD). This information will be used to correlate with technologies that the Department of Defense can offer. If you are part of the law-enforcement community, we will greatly appreciate your input. Tabulated results will be posted here after the survey is completed.

Personal Information (optional, for clarification if needed)

1. Your name: [ ]

2. E-mail: [ ]

3. Telephone: [ ]

Professional Background

4. Your specialty:

❍ SWAT team
❍ Bomb squad
❍ K-9 handler
❍ Narcotic/Gang Enforcement
❍ Negotiator
❍ Technology evaluator
❍ Administrator
❍ Other (specify below)

Other: [ ]

5. Your rank or title:

[ ]

6. Your agency and location:

[ ]

7. How long have you been in the Law-Enforcement field?

❍ 0-2 years ❍ 2-10 years ❍ Over 10 years

8. What is your background with respect to robotics?

- ❍ No experience
- ❍ Have looked into obtaining a robot
- ❍ Have used a robot in the past
- ❍ Currently have an EOD robot, looking to obtain another robot for other uses
- ❍ Currently have a non-EOD robot, looking to obtain another robot for other uses
- ❍ Currently have both EOD and non-EOD robots, still looking to obtain another robot
- ❍ Currently have robots that meet all my needs

Applications

9. Please give your estimate of the percentage of missions of the following types when a robot would be used, if available. (For example, a robot would be used in 90% of EOD missions, if available.)

a. Hostage rescue:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

b. Barricaded suspects:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

c. Inspection of hazardous areas:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

d. Delivery of high-risk warrants:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

e. Other scenarios and the percentage of missions when a robot would be used:

10. For the missions above, please give your estimates of:

(1) the percentage of the times when the following tasks would be performed, and
(2) the percentage of **those** times when a robot would be used, if available

For example, "Removing an explosive device" could be a task that is performed 10% of the times for the above missions (1), and 95% of the times that it is done, a robot would be used, if available (2).

a. Explosive breaching:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

b. Shattering windows:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

c. Opening doors:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

d. Observation/visual surveillance:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

e. Listening/audio surveillance:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

f. Delivery of small items (e.g., cell phone or food):
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

g. Passive remote communication (via remote speaker and microphone):
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

h. Delivering chemical agents:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

i. Retrieving small objects:
(1) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%
(2) ❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

j. Other tasks, percentage during above missions, and the percentage of times when a robot would be used:

11. Please give your estimate of the percentage of times when the following tools would be used by a robot, if available, to execute the tasks above:

a. A shotgun:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

b. A grenade launcher:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

c. Video camera (daylight):
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

d. Infrared/low-light video camera:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

e. Remote speaker and microphone:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

f. Articulated arm and grip:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

g. Less lethal weapons:
❍ 0-20% ❍ 20-40% ❍ 40-60% ❍ 60-80% ❍ 80-100%

What types? [ ]

h. Other tools and the percentage of missions when the robot would use them:

[ ]

Features

12. Please indicate the most appropriate values for the following features of a robot that would best meet your needs:

a. Maximum speed (first values are in miles/hour, second set in parentheses in feet/sec):
❍ under 1 (under 1.5) ❍ 1 - 2 (1.5 - 3) ❍ 2 - 3 (3 - 4.5) ❍ 3 - 4 (4.5 - 6) ❍ over 4 (over 6)

b. Most useful speed:
❍ under 1 (under 1.5) ❍ 1 - 2 (1.5 - 3) ❍ 2 - 3 (3 - 4.5) ❍ 3 - 4 (4.5 - 6) ❍ over 4 (over 6)

c. Weight (in pounds):
❍ 0 - 25 ❍ 25 - 50 ❍ 50 - 75 ❍ 75 - 100 ❍ over 100

d. Length (in inches):
❍ 0 - 12 ❍ 12 - 24 ❍ 24 - 36 ❍ 36 - 48 ❍ over 48

e. Width (in inches):
❍ 0 - 12 ❍ 12 - 24 ❍ 24 - 36 ❍ 36 - 48 ❍ over 48

f. Height (during transport, in inches):
❍ 0 - 12 ❍ 12 - 24 ❍ 24 - 36 ❍ 36 - 48 ❍ over 48

g. Maximum vertical reach (in feet):
❍ 0 - 2 ❍ 2 – 4 ❍ 4 – 5 ❍ 5 – 6 ❍ over 6

h. Operating distance / standoff (in feet):
❍ 0 - 50 ❍ 50 - 100 ❍ 100 - 200 ❍ 200 - 500 ❍ over 500

i. Mission duration (in hours):
❍ 0 – 1 ❍ 1 – 2 ❍ 2 – 3 ❍ 3 – 4 ❍ over 4

j. Manipulator lift capability (in pounds):
❍ 0 – 5 ❍ 5 – 10 ❍ 10 - 20 ❍ 20 - 40 ❍ over 40

k. Reasonable procurement cost for a robot with all the features you stated (in thousand dollars):
❍ 0 - 20 ❍ 20 - 40 ❍ 40 - 65 ❍ 65 - 100 ❍ over 100

l. Reasonable initial training time:
❍ 1 - 2 hours ❍ 2 - 8 hours ❍ 2 - 3 days ❍ 3 - 5 days ❍ over 5 days

m. Reasonable maintenance time per month (in hours):
❍ 0 – 1 ❍ 1 – 2 ❍ 2 – 4 ❍ 4 – 8 ❍ over 8

n. Reasonable annual maintenance cost (in dollars, for parts and contracted labor):
❍ 0 - 200 ❍ 200 - 500 ❍ 500 - 1000 ❍ 1000 - 2000 ❍ over 2000

o. Note or comments on specific features:

13. On a scale of 0 to 4, please indicate the importance of the robot being able to traverse the following terrain (4 is most important):

Bumpy dirt fields:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
High grass:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Sand:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Mud and snow:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Concrete curbs:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Rubble:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Stairs:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Loose indoor rugs / newspapers:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Loose telephone wires / television cables:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Crawlspaces:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Catwalks:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4

14. On a scale of 0 to 4, please indicate the importance of the following features (4 is most important):

Radio (RF) control link:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Fiber-optic control link:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Dual remote control links (RF and fiber):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Semiautonomous operation (operator issues high-level commands):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Small, handheld tactical video viewfinder:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Large viewing screen at command post:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Armored body:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Keep-away defensive mechanisms (tear gas, electric shocks, etc.):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Hidden deactivation switches:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Reconfigurable payloads/tools (modularity):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Ruggedness:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Weatherproof:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Off-the-shelf (non-unique) power sources:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Self-righting:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Backpackable / can be carried by one man:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
Ability to use more than one robot at once:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4

If you gave a non-zero answer to the last feature (use of more than one robot), please describe the scenarios where that would apply:

Other features and their importance:

Past experience

15. Please answer the following questions if you have used or are currently using a robot (otherwise skip to question 16):

a. What is the make and model of the robot?

b. How long have you had your robot?

c. How often do you use your robot?

d. How often do you train with your robot?

e. What percentage of non-EOD missions where you want to use your robot does it succeed in?

f. What factors helped you to decide on buying this robot?

g. What are the disadvantages/weaknesses of your current robot?

h. What are the solutions to the problems in (g)?

i. Which features would you look for in a second robot that would complement your current robot?

j. What currently available robot would best fit your needs for a *complementary* robot?

k. What currently available robot would best fit your needs for a *replacement* robot?

General interests

Although this survey has concentrated on mobile ground robots, to conclude the survey, we would like your opinion on the broader topic of surveillance robots.

16. On a scale of 0 to 4 (where 4 is strongest), please indicate your interests in the following types of surveillance robots:

A ground robot (wheeled or tracked):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
An aerial robot (UAV):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
An underwater robot (UUV):	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
A remote-controlled surface boat:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4
A pocket-sized robot that can be thrown or shot through a window:	❍ 0	❍ 1	❍ 2	❍ 3	❍ 4

17. Any other comments you would like to add, or any question you feel we have left out:

Thank you! Your input is greatly appreciated.

Submit **Erase Fields**

10 May 2000

APPENDIX B: TABULATED RESULTS, ENTIRE DATA SET

SPECIALTY:

SWAT:	30
Bomb disposal:	4
K-9 handler:	0
Narcotic/Gang Enforcement:	3
Negotiator:	1
Technology evaluator:	4
Administrator:	9
Other:	13

EXPERIENCE:

No experience:	38
Have looked into obtaining a robot:	4
Have used a robot in the past:	9
Currently have an EOD robot, looking for another robot:	10
Currently have a non-EOD robot, looking for another robot:	0
Currently have both types, looking for another robot:	1
Robotics needs are currently met:	2

SCENARIOS:

	0-20%	20-40%	40-60%	60-80%	80-100%
Hostage rescue:	29	9	15	5	5
Barricaded suspects:	9	9	10	24	11
Hazardous entry:	4	6	11	17	26
High-risk warrants:	37	11	6	7	1

TASKS and TASKS BY ROBOT:

	0-20%	20-40%	40-60%	60-80%	80-100%
Breaching:	41	9	8	3	1
Breaching by robots:	24	10	6	10	7
Shatter windows:	25	19	7	7	4
Shatter windows by robots:	22	15	11	6	3
Open door:	11	15	7	8	21
Open door by robots:	17	13	16	7	4
Observe:	5	8	6	16	27
Observe by robots:	5	13	11	17	12
Listen:	10	13	6	15	19
Listen by robots:	8	10	10	14	14
Delivery:	20	12	7	10	13
Delivery by robots:	6	2	10	17	22
Communication:	18	15	10	11	8
Communication by robots:	9	6	12	13	17
Chemicals:	22	17	10	10	3
Chemicals by robots:	21	8	14	7	6
Retrieve:	29	12	12	5	3
Retrieve by robots:	15	8	14	13	8

TOOLS:

	0-20%	20-40%	40-60%	60-80%	80-100%
Shotgun:	39	6	14	3	1
Grenade_launcher:	37	13	8	5	0
Video camera:	2	7	7	20	25
IR camera:	4	5	9	24	22
Speaker/Mike:	3	7	10	24	20
Arm&Hand:	9	6	14	17	17
Less-lethal:	20	12	15	9	7

FEATURES:

	0-1	1-2	2-3	3-4	>4
Max speed (mph):	3	9	20	20	11
Useful speed:	7	21	25	5	2

	0-25	25-50	50-75	75-100	>100
Weight (lbs):	10	13	19	12	8

	0-12	12-24	24-36	36-48	>48
Length (in):	3	16	28	12	1

Width (in):	5	37	17	2	0
Height (in):	8	14	29	8	1

	0-2	2-4	4-5	5-6	>6
Reach (ft):	1	4	12	22	22

	0-50	50-100	100-200	200-500	>500
Stand-off distance (ft):	1	4	13	28	16

	0-1	1-2	2-3	3-4	>4
Duration (hr):	0	3	11	12	37

	0-5	5-10	10-20	20-40	>40
Lift (lbs):	0	7	15	13	26

	0-20	20-40	40-65	65-100	>100
Cost ($K):	24	19	9	6	3

	1-2h	2-8h	2-3d	3-5d	>5d
Training time (hours/days):	2	20	29	5	6

	0-1	1-2	2-4	4-8	>8
Maintenance time (hours):	7	29	18	8	1

	0-200	200-500	500-1K	1K-2K	>2K
Maintenance cost ($):	9	18	20	11	4

TERRAIN:

	0	1	2	3	4
Bumpy dirt:	3	5	13	11	32
High grass:	4	5	8	18	29
Sand:	6	9	18	18	13
Mud & snow:	3	4	15	19	23
Curbs:	1	2	3	15	43
Rubble:	2	4	10	27	21
Stairs:	2	4	4	8	46
Rugs:	2	1	6	23	32
Wires:	1	2	10	21	30
Crawlspaces:	5	12	14	12	21
Catwalks:	4	17	23	8	11

GENERAL FEATURES:

	0	1	2	3	4
RF link:	2	2	5	14	42
Optical link:	3	4	12	24	21
Dual links:	3	1	13	15	31
Semiautonomy:	3	10	17	21	12
Viewfinder:	2	2	6	19	36
Large screen:	2	3	9	14	37
Armor:	5	4	11	17	28
Self defense:	4	9	17	19	16
Hidden switch:	5	8	11	15	26
Modular:	2	2	19	19	23
Rugged:	0	0	2	9	54
Weatherproof:	1	0	1	12	51
OTS power:	2	1	3	16	42
Self righting:	1	1	2	15	46
Backpackable:	5	8	14	16	22
Multirobot:	29	14	10	4	8

Robot types:

	0	1	2	3	4
UGV:	2	1	6	12	43
UAV:	19	13	14	6	11
UUV:	39	14	4	2	3
USV:	38	14	4	2	3
Throwbots:	7	7	12	16	20

APPENDIX C: TABULATED RESULTS, RESPONDENTS REPORTING PRIOR ROBOTICS EXPERIENCE

SPECIALTY:

SWAT:	13
Bomb disposal:	3
K-9 handler:	0
Narcotic/Gang Enforcement:	0
Negotiator:	1
Technology evaluator:	2
Administrator:	3
Other:	4

EXPERIENCE:

No experience:	0
Have looked into obtaining a robot:	4
Have used a robot in the past:	9
Currently have an EOD robot, looking for another robot:	10
Currently have a non-EOD robot, looking for another robot:	0
Currently have both types, looking for another robot:	1
Robotics needs are currently met:	2

SCENARIOS:

	0-20%	20-40%	40-60%	60-80%	80-100%
Hostage rescue:	7	4	8	3	3
Barricaded suspects:	2	3	4	11	5
Hazardous entry:	2	2	6	7	9
High-risk warrants:	17	3	2	1	1

TASKS and TASKS BY ROBOT:

	0-20%	20-40%	40-60%	60-80%	80-100%
Breaching:	15	5	5	0	0
Breaching by robots:	10	5	3	4	0
Shatter windows:	7	7	5	5	1
Shatter windows by robots:	11	4	4	2	1
Open door:	2	5	3	7	8
Open door by robots:	8	4	7	2	1
Observe:	0	3	1	10	11
Observe by robots:	1	4	4	7	7
Listen:	1	5	3	8	9
Listen by robots:	3	3	1	7	7
Delivery:	3	7	4	6	5
Delivery by robots:	0	1	3	8	10
Communication:	5	8	3	6	3
Communication by robots:	1	5	4	5	7
Chemicals:	7	5	6	6	1
Chemicals by robots:	10	2	6	2	1
Retrieve:	9	6	8	1	1
Retrieve by robots:	7	2	6	4	3

TOOLS:

	0-20%	20-40%	40-60%	60-80%	80-100%
Shotgun:	14	4	5	1	1
Grenade_launcher:	15	4	5	1	0
Video camera:	0	0	2	11	11
IR camera:	1	0	3	11	11
Speaker/Mike:	1	1	4	11	9
Arm&Hand:	1	3	5	10	6
Less-lethal:	9	3	8	3	2

FEATURES:

	0-1	1-2	2-3	3-4	>4
Max speed (mph):	0	4	9	8	5
Useful speed:	3	8	10	1	1

	0-25	25-50	50-75	75-100	>100
Weight (lbs):	3	7	4	5	6

	0-12	12-24	24-36	36-48	>48
Length (in):	1	3	14	7	0
Width (in):	3	12	10	0	0
Height (in):	5	3	12	4	0

	0-2	2-4	4-5	5-6	>6
Reach (ft):	0	3	4	7	11

	0-50	50-100	100-200	200-500	>500
Stand-off distance (ft):	1	0	4	11	10

	0-1	1-2	2-3	3-4	>4
Duration (hr):	0	1	4	6	15

	0-5	5-10	10-20	20-40	>40
Lift (lbs):	0	4	5	4	12

	0-20	20-40	40-65	65-100	>100
Cost ($K):	6	9	3	6	2

	1-2h	2-8h	2-3d	3-5d	>5d
Training time (hours/days):	1	9	11	1	4

	0-1	1-2	2-4	4-8	>8
Maintenance time (hours):	4	11	8	3	0

	0-200	200-500	500-1K	1K-2K	>2K
Maintenance cost ($):	4	8	4	6	3

TERRAIN:

	0	1	2	3	4
Bumpy dirt:	3	2	7	5	9
High grass:	3	3	1	8	11
Sand:	2	4	6	6	8
Mud & snow:	1	3	11	4	7
Curbs:	0	1	1	4	20
Rubble:	0	3	6	10	7
Stairs:	1	2	2	2	19
Rugs:	1	0	2	11	12
Wires:	0	0	3	12	11
Crawlspaces:	3	3	6	8	6
Catwalks:	1	7	9	6	3

GENERAL FEATURES:

	0	1	2	3	4
RF link:	0	0	3	7	16
Optical link:	0	2	5	11	8
Dual links:	0	0	5	8	12
Semiautonomy:	0	4	11	6	4
Viewfinder:	0	1	4	7	14
Large screen:	0	1	3	9	13
Armor:	4	2	4	8	8
Self defense:	2	4	7	8	5
Hidden switch:	2	4	4	4	12
Modular:	0	0	6	7	13
Rugged:	0	0	1	2	23
Weatherproof:	0	0	0	8	18
OTS power:	0	1	2	7	16
Self righting:	0	1	0	5	20
Backpackable:	1	5	9	5	6
Multirobot:	8	6	7	1	4

Robot types:

	0	1	2	3	4
UGV:	0	0	3	4	19
UAV:	11	6	3	2	4
UUV:	16	5	0	2	2
USV:	16	4	3	1	1
Throwbots:	4	2	6	3	10

APPENDIX D: TABULATED RESULTS, RESPONDENTS REPORTING NO ROBOTICS EXPERIENCE

SPECIALTY:

SWAT:	17
Bomb disposal:	1
K-9 handler:	0
Narcotic/Gang Enforcement:	3
Negotiator:	0
Technology evaluator:	2
Administrator:	6
Other:	9

EXPERIENCE:

No experience:	38
Have looked into obtaining a robot:	0
Have used a robot in the past:	0
Currently have an EOD robot, looking for another robot:	0
Currently have a non-EOD robot, looking for another robot:	0
Currently have both types, looking for another robot:	0
Robotics needs are currently met:	0

SCENARIOS:

	0-20%	20-40%	40-60%	60-80%	80-100%
Hostage rescue:	22	5	7	2	2
Barricaded suspects:	7	6	6	13	6
Hazardous entry:	2	4	5	10	17
High-risk warrants:	20	8	4	6	0

TASKS and TASKS BY ROBOT:

	0-20%	20-40%	40-60%	60-80%	80-100%
Breaching:	26	4	3	3	1
Breaching by robots:	14	5	3	6	7
Shatter windows:	18	12	2	2	3
Shatter windows by robots:	11	11	7	4	2
Open door:	9	10	4	1	13
Open door by robots:	9	9	9	5	3
Observe:	5	5	5	6	16
Observe by robots:	4	9	7	10	5
Listen:	9	8	3	7	10
Listen by robots:	5	7	9	7	7
Delivery:	17	5	3	4	8
Delivery by robots:	6	1	7	9	12
Communication:	13	7	7	5	5
Communication by robots:	8	1	8	8	10
Chemicals:	15	12	4	4	2
Chemicals by robots:	11	6	8	5	5
Retrieve:	20	6	4	4	2
Retrieve by robots:	8	6	8	9	5

TOOLS:

	0-20%	20-40%	40-60%	60-80%	80-100%
Shotgun:	25	2	9	2	0
Grenade_launcher:	22	9	3	4	0
Video camera:	2	7	5	9	14
IR camera:	3	5	6	13	11
Speaker/Mike:	2	6	6	13	11
Arm&Hand:	8	3	9	7	11
Less-lethal:	11	9	7	6	5

FEATURES:

	0-1	1-2	2-3	3-4	>4
Max speed (mph):	3	5	11	12	6
Useful speed:	4	13	15	4	1

	0-25	25-50	50-75	75-100	>100
Weight (lbs):	7	6	15	7	2

	0-12	12-24	24-36	36-48	>48
Length (in):	2	13	14	5	1
Width (in):	2	25	7	2	0
Height (in):	3	11	17	4	1

	0-2	2-4	4-5	5-6	>6
Reach (ft):	1	1	8	15	11

	0-50	50-100	100-200	200-500	>500
Stand-off distance (ft):	0	4	9	17	6

	0-1	1-2	2-3	3-4	>4
Duration (hr):	0	2	7	6	22

	0-5	5-10	10-20	20-40	>40
Lift (lbs):	0	3	10	9	14

	0-20	20-40	40-65	65-100	>100
Cost ($K):	18	10	6	0	1

	1-2h	2-8h	2-3d	3-5d	>5d
Training time (hours/days):	1	11	18	4	2

	0-1	1-2	2-4	4-8	>8
Maintenance time (hours):	3	18	10	5	1

	0-200	200-500	500-1K	1K-2K	>2K
Maintenance cost ($):	5	10	16	5	1

TERRAIN:

	0	1	2	3	4
Bumpy dirt:	0	3	6	6	23
High grass:	1	2	7	10	18
Sand:	4	5	12	12	5
Mud & snow:	2	1	4	15	16
Curbs:	1	1	2	11	23
Rubble:	2	1	4	17	14
Stairs:	1	2	2	6	27
Rugs:	1	1	4	12	20
Wires:	1	2	7	9	19
Crawlspaces:	2	9	8	4	15
Catwalks:	3	10	14	2	8

GENERAL FEATURES:

	0	1	2	3	4
RF link:	2	2	2	7	26
Optical link:	3	2	7	13	13
Dual links:	3	1	8	7	19
Semiautonomy:	3	6	6	15	8
Viewfinder:	2	1	2	12	22
Large screen:	2	2	6	5	24
Armor:	1	2	7	9	20
Self defense:	2	5	10	11	11
Hidden switch:	3	4	7	11	14
Modular:	2	2	13	12	10
Rugged:	0	0	1	7	31
Weatherproof:	1	0	1	4	33
OTS power:	2	0	1	9	26
Self righting:	1	0	2	10	26
Backpackable:	4	3	5	11	16
Multirobot:	21	8	3	3	4

Robot types:

	0	1	2	3	4
UGV:	2	1	3	8	24
UAV:	8	7	11	4	7
UUV:	23	9	4	0	1
USV:	22	10	1	1	2
Throwbots:	3	5	6	13	10

INITIAL DISTRIBUTION

Defense Technical Information Center
Fort Belvoir, VA 22060–6218 (4)

SSC San Diego Liaison Office
Arlington, VA 22202–4804

Center for Naval Analyses
Alexandria, VA 22302–0268

Office of Naval Research
ATTN: NARDIC (Code 362)
Arlington, VA 22217–5660

Government-Industry Data Exchange
Program Operations Center
Corona, CA 91718–8000

Defense Advanced Research Projects Agency
Information Technology Office
Arlington, VA 22203 (2)

Defense Advanced Research Projects Agency
Advanced Technology Office
Arlington, VA 22203

Naval Explosive Ordnance Disposal
Technology Division
Indian Head, MD 20640–5070

U.S. Army Aviation and Missile Command
Redstone Arsenal, AL 35898–8060

U.S. Army Infantry Center
Ft Benning, GA 319051

U.S. Army Maneuver Support Center
Ft. Leonard Wood, MO 65473–8929

Battelle Memorial Institute
Columbus, OH 43201

National Institute of Justice
Washington, DC 20531 (53)

National Law Enforcement and Corrections
Technology Center National
Rockville, MD 20850

National Law Enforcement and Corrections
Technology Center Northeast
Rome, NY 13441

National Law Enforcement and Corrections
Technology Center Southeast
North Charleston, SC 29418 (5)

National Law Enforcement and Corrections
Technology Center Rocky Mountain
Denver, CO 80208

National Law Enforcement and Corrections
Technology Center West
El Segundo, CA 90245 (3)

Border Research and Technology Center
San Diego, CA 92101–4912 (5)

National Institute of Standards and Technology
Office of Law Enforcement Standards
Gaithersburg, MD 20899

Wheeling Jesuit University
Office of Law Enforcement
Technology Commercialization
Wheeling, WV 26003

University of Central Florida
National Center for Forensic Science
Orlando, FL 32816–2367 (4)