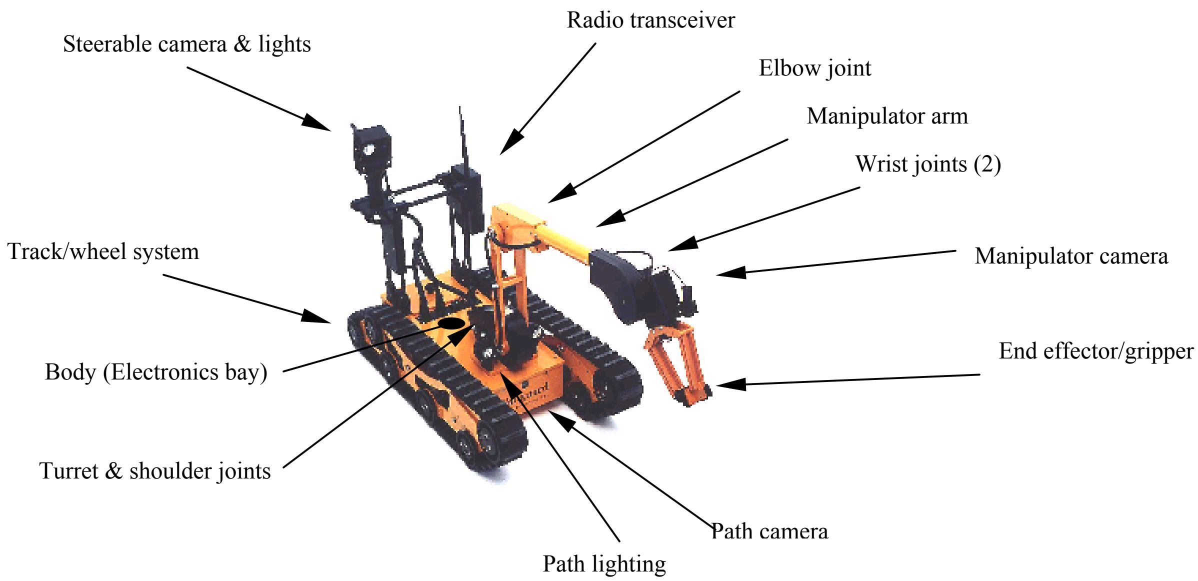
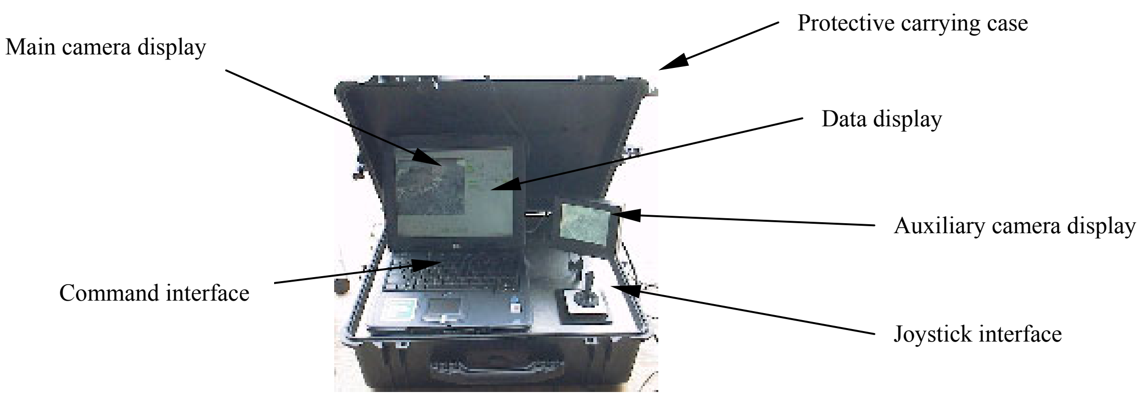
AVAILABLE ROBOTIC SYSTEMS

Introduction to Robotic Systems

A robotic system consists of a vehicle to carry a payload and an operator control station (OCS) for tele-operation. The vehicle is designed for specific mobility needs such as high-speed travel, traversing rough terrain, and/or maneuvering in small spaces. The payloads are typically a manipulator or an end effector on an arm, sensors, and actuators. Payloads could include an X-ray camera, chemical-agent detector, drug-detection devices, bomb-disarming systems, and so forth. The OCS displays feedback from the vehicle, typically video, and provides controls to operate the vehicle.



Robot Vehicle



Operator Control Station

By permission of EOD Performance

Robot Vehicle Features

Robot vehicle features include the subsystems that enable the robot to perform missions as a tele-operated vehicle. These include the subsystems that provide mobility and remote-object manipulation. They also include the subsystems that provide operator feedback for controlling the vehicle remotely.

Mobility System

The mobility system consists of tread tracks or wheels powered by drive motors. Some vehicles have track extensions that add additional tread length to either lift the vehicle for additional arm height or aid in stair or obstacle climbing. The track length and the slope of the leading pulley arrangement determine the pitch of stairs that the vehicle can climb. However, vehicles with longer track length are less able to turn in tight quarters. Vehicles are capable of turning about their center (zero-radius turn) by driving the tracks in opposite directions.

By permission of iRobot

Wheels can be added for faster speeds on smooth or paved roads. Typically, wheels are manually bolted onto a hub of the track system, raising the treads from contacting the ground. Ideally, the track extensions or wheels should be remotely deployable.

Manipulator Arm

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The manipulator arm is for moving payloads. An end effector, typically a gripper, is used in applications such as placing sensors or retrieving items and for dexterous movements such as opening a door, using a tool, and positioning equipment. A further use is to extend the visual range of the vehicle by mounting a camera on the end of the manipulator. This might be done, for example, to look into overhead luggage compartments. The manipulator should have at least 5 degrees of freedom, meaning the end effector can be moved in any of the three coordinate directions and rotate around both a vertical axis and a horizontal axis. This is accomplished by motorized joints in the manipulator-arm links including a "turret," “shoulder,” “elbow,” “wrist twist,” and “wrist rotation.” The gripper should be able to squeeze between the “fingers” and grasp a cylindrical object such as a pipe bomb.

Vehicle Control Systems

Robotic device control electronics can be a proprietary processor, a standard microprocessor, or a standard personal computer (PC) processor. Among these processors there are differences in cost, weight, flexibility, and expandability. The proprietary processor is the least expensive, the lightest, the least flexible, and the least expandable of the processors, and the PC processor is the most expensive, heaviest, most flexible, and most expandable of the processors. Flexibility and expandability are desirable for future enhancements, features, and options. This makes the PC processor a good choice if the cost and weight of the overall robotic device meets necessary requirements. Further, the PC processor uses a more common programming language than the others, making it more universally serviceable on an engineering level if custom functionality is desired.

The communication link is a major subsystem in vehicle control. Several schemes are used. Video data use relatively high bandwidth (5 MHz) for frame rates sufficient to prevent jerky motion, whereas commands and audio and sensor data require less bandwidth (20 KHz). One of two popular techniques is to use two transceivers, one high-frequency channel for the large video bandwidth, typically 2.4 GHz, and the other a low-frequency channel, 900 MHz for example, for the relatively low data rate of the commands. FM transceivers are common, and video data are susceptible to signal loss that causes pauses or jumping of the picture. The second technique uses a single transceiver with a wireless Ethernet 802.11 protocol. This technique is a digital transmission method, and loss of signal is not as noticeable. This transmission uses spread spectrum modulation, in which the video is carried on the main frequency, and the other data use a sideband. This technology is more adapted to a PC controller and is not as widely deployed as the other types of controllers.

In addition to radio frequency links, cable tethers are used. Two types are available, optical-fiber and wire cable. Optical fiber is generally smaller and more lightweight than wire, and it has higher bandwidth to support longer transmission distances.

The fire control system, although a minor feature for most missions, is noteworthy because of the safety concern. For firing bomb disruptors, the fire control circuit should be failsafe with the use of at least two actuations from the control station and at least two mechanical switches that cannot fail at the same time in the fire position.

Robotic systems must operate in environments with extreme temperatures. Further, the vehicle itself produces heat from the controller and drive motors. The vehicle's electronics bay should be equipped with a temperature control system that usually cools the device, but can also heat it.

Video, Lighting, and Audio Systems


By permission of Mesa Association.

At a minimum, the vehicle needs a forward-looking camera for the operator to see the path. Generally, robotic devices have a number of cameras to provide good situational awareness and other specific cameras to provide detailed viewing. Typically, there is a steerable color camera or a 360-degree panoramic camera. Additionally, a manipulator-arm mounted camera provides "snooping" capability or can be used to aim disruptors. One or more of these cameras should have zoom capability, typically 10X or greater optical and 100X or greater digital. However, digital zoom capability sacrifices resolution and is not recommended at extremely high powers. All cameras should have auto focus and either mechanical or electronic auto iris capability. The typical resolution of these cameras is 320 x 240 at 15 frames per second (FPS). Lighting is generally provided for each camera. Lighting should be dimmable from full brightness to off. High-intensity white light-emitting diodes (LEDs) are used for weight and energy savings. Infrared lighting and cameras are occasionally used. Vehicle audio capability usually includes a microphone and speaker. Audio compression is employed to reduce signal transmission bandwidth and provides a sound quality similar to portable telephones.

Modularity and Compatibility

For serviceability as well as transportability, the ability to remove the tread track assemblies and the manipulator-arm assembly from the body (usually the electronics bay) is desirable. These should be self-contained assemblies attached with a few captured fasteners and cables with electrical connectors that plug into a bulkhead on the body. The electronics in the body bay should ideally contain plug-in circuit boards similar to a PC. Fastener-mounted circuit boards with cable connectors are an alternative. Other electronics, such as power supplies, motor controllers, and so forth, should also be easily removable. The electronics should be designed so that the field-replaceable units are at a subassembly level no lower than a circuit board or off-the-shelf item and a level no higher than a removable electronics rack in the robot body. The vehicle battery should be changeable in a few minutes without the use of tools. Multiple batteries should be used if necessary to keep the weight of each battery pack under a few pounds. A vehicle carrying case should be a standard accessory.

Compatibility has several elements. Modular features on robotic devices should be interchangeable among vehicles. Also, the components should be readily available from several sources whenever possible. Batteries, PC components, cameras, lights, and so forth should be designed to use consumer products when practical. Finally, a vehicle should be controllable from any control station with the proper radio frequency set-up. Controllers and vehicles should have a selection of broadcast channels that allow fleet control without interference. A software protocol standard has been set forth for military robotic devices with the objective of enabling any manufacturer's controller to command any other manufacturer's vehicle. This is the Joint Architecture for Unmanned Ground Systems (JAUGS). This protocol is being required in military contracts, but is in its infancy; no commercial cross-manufacturer control has yet been demonstrated.

Sensor, Actuator, and Other Auxiliary Devices

Payloads such as sensors and actuators typically have electrical data outputs or actuation command inputs that must be communicated to or from the OCS. These signals must therefore interface with the robotic vehicle. Standard communication protocols and hardware are primarily used, and, therefore, the robotic vehicle should have one or more RS232 (a wiring protocol), Universal Serial Bus (USB), or Ethernet ports. It should have power jacks, typically 12 VDC, for external devices, as well as a battery-charger jack. There should also be quick-connect firing circuit terminals such as "radio speaker jacks" capable of handling 2 amps of current.

Operator Control Station Features

The OCS features include the subsystems that provide the ability to control the vehicle and payloads to perform the mission. Direct controllers include the subsystems that provide the man-machine interfaces for remotely controlling the robotic device and getting feedback.

Mobility Control

There are several techniques for controlling robotic motion. Two of the more popular techniques are "direct" control and "proportional" control. Direct control provides "go" and "stop" commands, and the robot moves at a given speed. These controllers usually provide the ability to select from three speeds, for example, slow, fast, and very fast. Reverse is also provided. The go, stop, and speed commands on the simplest controllers are issued with single keystrokes or buttons. Turning commands are likewise initiated with keystrokes: a single stroke is a little turn and several strokes are a sharper turn. Proportional controls have continuously variable speed and steering adjustments in which the motion is *proportional* to the movement of the interface device, typically a joystick or PC mouse. If the interface device is moved a little forward, the vehicle moves slowly forward. If the interface device is moved a great deal to the left, the vehicle moves at a fast speed in a sharp left turn. This user interface is well known from video games. A proportional control system is more intuitive and requires less effort and concentration to use, but is typically more expensive.

Manipulator Control

The manipulator is typically commanded using a direct control system at a fixed speed. The interface device can be keystrokes, buttons, or a joystick. Here, the interface type makes little difference because the commands are discrete motions such as arm left/right, arm up/down, arm in/out, gripper open/closed, and so forth. Most of the links and joints in the manipulator provide circular motions so that arm commands are not strictly up/down or in/out. An up command, for example, is actually a shoulder-joint command that is a rotary motion. The arm also moves a little in or out as well. Therefore, when navigating to a precise target, like a key in a lock, a difficult iteration of commands is necessary. In more elaborate controllers, this is alleviated by the controller calculating the combination of motions required to move the gripper in a straight line. With a system like this, the user can command linear motion. A further refinement is the ability to use a coordinate system. The operator could define a zero X, Y, Z location and then command the gripper to go to a measured location using keyboard-entered coordinates.

Video, Lighting, Audio, and Navigation Control

The control of functions in the video and lighting systems is basic, particularly controlling the lighting and the direction of the steerable camera(s), often referred to as the "pan/tilt" camera(s). These systems' display of information is of greater importance because they are the eyes and ears of the operator. As mentioned earlier, there are typically three cameras with corresponding lighting. The operator display console should display images in such a way that the operator is aware of all the data without being overwhelmed. The best display technique is a thumbnail image from all cameras and a large main display of one image. The operator should be able to select a desired image from the thumbnails and display it by pushing a button or selector switch. Camera iris control should be automatic, with an operator switch and/or knob for manual operation.

Camera auto-focus control is internal to the camera and generally not accessible by the operator. The video display should be daylight readable with backlighting for night viewing.

Two-way audio should have a toggle switch (stays on or stays off) for listening and a momentary switch (must be held on) for talking. For both audio and video, the controller should have output jacks for recording on external devices.

Navigation systems that provide the operator with robot location and heading are used on the more advanced systems. These tools include electronic compasses, global positioning systems (GPSs), range-finders, and so forth.

Other Features

Disruptor fire control should be controlled with two cover-protected switches. One switch arms the circuit, and the other switch fires the device. For added safety, there may also be a software command; however, the arm and fire controls should be mechanical switches.

The OCS should be battery powered with a jack to recharge the battery or power the controller. There is often a jack for an external high-powered antenna. The OCS enclosure should be a lightweight portable unit that is watertight for use in rain or decontamination. A backpack should be an optional accessory.

Available Systems

Numerous commercial off-the-shelf (COTS) robots are available in a range of sizes and abilities. Vehicles range from units small enough to be thrown, which are used strictly for surveillance, to large all-terrain vehicles (ATVs) for carrying or towing huge payloads. This report illustrates a selection process for small to mid-sized robot systems only. This is based on a cursory examination of the transit requirements of the previous section. These robot systems will meet most of the terrain and obstacle requirements, specifically size and weight requirements for the defined environment, as well as man transportability requirements. Also, these robot systems are priced within the budget of an organization equivalent to a local government agency. Further, this report focuses on selecting a single multipurpose system meeting the most number of requirements, rather than selecting a family of robot systems spanning all requirements, because owning a family of robotic devices is not within the budget of most transit organizations. Therefore, a list of small to mid-sized candidates is compiled in Table 2, and their fit to transit requirements is discussed in the section on selection analysis.

CANDIDATE ROBOT CRITICAL FEATURE TABLE

Table 2

Manufacturer	Name of Robot	Country of Origin	Vehicle Weight OCS (lb)	Length (inch)	Width (inch)	Height (inch)	Drive & Speed (mph)	Control Link* & Range (miles)	Arm Lift Extended (lbs)	Arm Lift Retracted (lbs)	Reach Horiz. Vert. (inch)	Stair Climb	Max Grade (deg)	Cost ($K)
AB Precision (Poole) Ltd.	Cyclops L.E.	UK	59.5	34.5	15.6	8.25	Track 1	Cable 1.1		11		Y		85
	Cyclops Mk4C	UK	88.2	34.2	19.3	8.25	Track 3.4	RF 8.5 FO		11		Y		120
	Lynx	UK	39.7	25.5	17.75	17.75	Wheel 1.2	Cable .28				N		25
	Groundhog	UK					Wheel	RF				N		58
	Bison	UK					Wheel	RF				N		88
Angelus Research	Intruder	USA	42	22	17	10	Rollers 1	RF .6	No Arm	No Arm	No Arm	N	6-8	10
	ART	USA	40	22	13	7	Track 1	RF .9	No Arm	No Arm	No Arm	N	6-8	
Cybernetix (Giat)	TSR 202	FR	594	47.25	26.4	39	Track 2.5	RF 2.2 Cable 1.3	26.5	154	93.6	Y	40	150
	Track Castor Wheel	FR	92.6 61.7	31.4 26.8	15.7 15.7	15.7 16.9	Track 1.5 Wheel 1.5	RF 2.2 Cable 1	11	22	43	Y N	30	
	Track RM 35 Wheel	FR	165	33.1	23.3	19.7	Track 1.7 Wheel 1.7	RF 2.2 Cable 1.3	11	31	57	N	30	
EOD Performance	Vanguard	CAN	95	36	17	16	Track .75 Wheel	RF Cable .75	20	40	38 52	Y	38	25
Engineering Tech. Inc.	RATLER	USA	33	22	19.6	12	Wheel 2.3	RF 5.2	No Arm	No Arm	No Arm	N		
Foster-Miller	Talon	USA	85	34	22.5	11	Track 4	RF 1 FO	30	40	53	Y	45	60
	Solem	USA	48	20	14.75	8	Track 1	RF 1	No Arm	No Arm	23	Y	45	41
	Ferret	USA	480	57.5	26.5	57.5	Track 1.5	RF .4 Cable						
HDE MFG	MURV-100	USA	49.6	23.8	17	4.5	Wheel .8	RF 5 FO	20	35	60	N		25
HighCOM Security	MR-5	CAN	550	50	26.7	31.5	Track 7.3 Wheel 7.3	RF Cable .1	44	130	67 95	Y		
Inuktun	MicroVGTV	USA		12.5	6.5	2.5	Track .2	Cable .02	No Arm	No Arm	No Arm	N		15
	MDV	USA	90.4	23.6	14.2	16.6	Track .4	Cable .56	No Arm	No Arm	No Arm	N		40
iRobot	Icecap	USA	52	24	20	6.5	Track 4.9	RF .4 FO 1.3	TBD	TBD	78	Y	60	85

(Table 2 continued)

Manufacturer	Name of Robot	Country of Origin	Weight Vehicle OCS (lb)	Length (inch)	Width (inch)	Height (inch)	Drive & Speed (mph)	Control Link* & Range (miles)	Arm Lift Extended (lbs)	Arm Lift Retracted (lbs)	Reach Horiz. Vert. (inch)	Stair Climb	Max Grade (deg)	Cost ($K)
Kentree	Brat	IRE	125 Track 121 Wheel	35.4	20	20.9	Track 1.5 Wheel 4	RF 1.7 Cable	13.2	18	47	Y	42 wheel 45 track	62
	Hobo	IRE	502	57.8	27.6	34.7	Wheel 2.5	Cable 1.4	66.1	165	59	Y	42	120
	Rascal	IRE	72.8	31	16.2	13.6	Wheel 1.6	RF 1.7 Cable	No Arm	No Arm	No Arm	N	35	48
	Imp	IRE	165.3	31.4	16.6		Track .45	RF 1.7 Cable	11	22		Y	45	62-70
Mesa Associates	MATILDA	USA	98	26	20	12	Track 2.1	RF 1.4	25	25	42	Y	45	66
OAO Robotics (Lockheed-Martin)	MPR 150	USA	218.3	38	23.5	31	Track 1.5	User Spec. 9		60		Y		90
	Recorm	USA	99.2	37	24	25	Wheel 3	User Spec. 9						150
Pedsco	RMI 10	CAN	141.1	32.3	21.6	19.7	Wheel 2.5	RF 1.7 Cable	75	75	77 118	N	45	50
	RMI 9	CAN	264.6	41.3	24.4	26.8	Wheel 2.5	RF 1.7 Cable	180	180	140 144	Y	45	60
Remotec (Northrop Grumman)	Andros F5A	USA	550	35.3	27.6	41	Track 2.0	RF 4.3 Cable	60	100	64 92	Y	45	75.5
	Andros F6A	USA	350	49	17.5	44	Track 3.5	RF 1.7	25	60	48 84	Y	45	63.4
	Andros Mini	USA	190	42	24	37	Track 1.1	RF 1.1 FO	15	40	45 87	Y	45	60
	Wolverine	USA	597.4	57.2	27.6	39.4	Track 2.0	RF 4.3	60	100	64 100	Y	45	66.4
Ricardo	Brawn	UK	440.9	24.4	29.5	33.8	Track	RF FO	50.7	51				
ROV Tech.	SCARAB IIA	USA	125	35	14	10	Track .57	Cable .22				Y		87
Terra A.C.	Predator	USA	520	39.6	29	25	Wheel	RF 1.6 Cable		40				
	Merlin	USA	60	30	17.3	15.6	Track	RF .5 Cable		20				25
	Scorpion	USA	55	30	16.2	9	Track	RF .5 Cable	NA	NA				15

* Control link is the link between the operator control station and the robot vehicle. “RF” is radio frequency, “FO” is a fiber-optic cable, and "Cable” is a wire cable. The RF distances are line-of-sight.

SELECTION ANALYSIS

Selection Rationale

Many comparative studies on robot systems have been performed in the past. Some have examined highly specialized robots such as tele-operated road construction equipment and small stealth fleet robots for gathering large-area intelligence. Competitions among research and academia robots such as RoboRescueCup have provided another arena for comparison. For the most part, however, homeland security studies have had similar requirements to this study and resulted in similar selections. To provide objective evaluations of performance, a standardized testing course is used such as that built by the National Institute of Standards and Technology (NIST). A standardized testing course could include overturned furniture, collapsed floors, broken pipe, and mannequin victims. Agencies such as the Center for Robot-Assisted Search and Rescue (CRASAR) at the University of South Florida, using such test courses, have selected a group of robot systems that have demonstrated their performance at the World Trade Center rescue effort and other emergency robotic mobilizations. Other programs, such as the military competition, MTRS, presently in progress, have attracted these same candidates. These programs and selecting agencies have fairly consistently chosen a small group of robot systems for search and rescue, explosive ordnance device (EOD) detection and disposal, and perpetrator location and stabilization.

Robotic device requirements for transit applications are very similar to requirements for military and EOD applications except that the application environment is more specific. Although transit vehicles have a myriad of configurations, the main difference in requirement specifications for robotic devices in the transit environment is stair-climbing ability in tight quarters. Available candidates can be sorted by comparing the transit environment requirements specification, Table 1, with the available robotic systems, Table 2. Some robot systems met most of the requirements but have one severe shortcoming: typically a delicate (non-robust) design (which compromises survivability), the lack of a manipulator arm, or a lack of articulation (degrees of freedom) in the manipulator arm. Width, turning radius, and weight were other severe shortcomings for a generic solution.

It should be emphasized that this illustration of initial robot identification is based on manufacturers' marketing literature and that the selection analysis is a best-fit effort rather than a one-for-one comparison of requirements and specifications. In any robotic device selection process, demonstrations of candidate systems should be performed before final selection and purchase.

Robot systems not chosen as good all-in-one solutions should be considered if the need arises for specialized missions utilizing their abilities or if a specific requirement not met by the systems is of greater importance to the end user than recognized here.

As with any major purchase of a product produced by several manufacturers, a comparison demonstration should be performed as a final evaluation. The available systems have unique strengths and weaknesses, and these need to be weighed by an end user in an actual environment.

Operator Demands, Training, and Maintenance

Demands on the operator of a robotic device start with deployment. Robot systems for consideration should be man transportable, meaning they weigh from 50 to 100 lbs, and, the entire system, including OCS and accessories, can be carried by two people. Deployment can be as demanding as throwing the robot vehicle through a window or backpacking it to a remote area. Operational demands, on the other hand, are not as physical as deployment demands. However, operational demands require mental concentration, good manual dexterity, the ability to multitask, and the ability to process input from a number of sources. As an example, an operator might have to precisely guide the manipulator to place a sensor next to a suspect package in tight quarters, monitor two other cameras for encroaching fire or perpetrators, and listen for sounds of survivors. In addition to the abilities listed above, operating the vehicle and manipulator to a fine degree of control takes practice. Operators should be selected who not only possess the skills required for the mission, but who are also proficient at similar hand-eye coordination tasks such as operating radio-controlled model cars or planes. Training will then be mostly a matter of learning the robot system features; just a few hours will be needed to become familiar with the feel of the controls. Manufacturers provide training courses for learning the system features and capabilities. A typical two-day course costs about $3,000 per person. The curriculum includes the following:

- OCS set-up, operator controls, display screen functions, and radio link theory;
- Vehicle set-up, major components and modules installation, fiber-optic use, camera use, auxiliary systems use, manipulator and gripper capabilities, and battery charging and care; and
- Practical training in packing and setting up, basic operation, practice missions, and trouble-shooting, and providing a question and answer session.

Usually training is held at the manufacturer's location in classes for multiple purchasers. Training can be arranged at the users' location if tuition for many students is purchased or if the trainer's transportation and accommodation expenses are paid.

Maintenance contracts are also available for extending the typical 90-day warranty. These contracts vary with manufacturer size. Smaller manufacturers require the device to be sent to their factory; larger manufacturers have 24-hour turn-around field service. The yearly price is typically 5% to 10% of the sales price. Maintenance training is available from larger manufacturers and is about the same cost as user training.

EOD and NBC accessories such as X-ray equipment, chemical agent detectors, nuclear sensors, and so forth should be considered along with the purchase of a robotic system. These can sometimes be purchased or recommended through the robot manufacturer or found on the Internet. An independent purchase should be coordinated with the robot system manufacturer for mechanical and electrical compatibility.

GLOSSARY

ATV – all-terrain vehicle
COTS – commercial off-the-shelf
CRASAR – Center for Robotic-Assisted Search and Rescue
Degrees of freedom – linear and rotational directions in which a mechanism can move
Digital zoom – enlargement of a digital picture by enlarging the picture elements in the display
Disruptor – pneumatic or hydraulic cannon for destroying an ordnance detonating system
End effector – mechanism on the end of a manipulator arm, specialized for performing tasks such as gripping or connecting to a piece of equipment
EOD – explosive ordnance device
Ethernet – communication protocol for computing devices
FPS – frames per second
GPS – global positioning system
GHz – gigahertz
Infrared – wavelength of light below visibility level, usually associated with heat
JAUGS – Joint Architecture for Unmanned Ground Systems
KHz – kilohertz (one thousand cycles per second)
LED – light-emitting diode
Manipulator arm – multijointed mechanism for moving an end effector or payload
MHz – megahertz (one million cycles per second)
MTBF – mean time between failure
MTRS – Man Transportable Robotic System (a NAVSEA program)
MTTR – mean time to repair
NAVSEA – Naval Sea Systems Command
NBC – nuclear, biological, chemical
NIJ – National Institute of Justice
NIST – National Institute of Standards and Technology
OCS – operator control station
Optical fiber – a glass or plastic fiber for communicating using light pulses
Optical zoom – enlargement of a digital image by optically magnifying the image presented to the digitizer
PC – personal computer
Radio link – a communication means between two pieces of equipment over a transmitter/receiver
RS232 – wiring protocol for electronics communication
Tele-operated – equipment operated from a distance
TSWG – Technical Support Working Group
USB – Universal Serial Bus
VDC – Volts Direct Current

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   JAUGS
   www.jauswg.org

   NAVSEA MTRS
   www.ih.navy.mil/contracts/ MTRS%20Questions%20and%20Answers.pdf

   NIJ Final Report on Law Enforcement Robot Technology Assessment
   www.nlectc.org/jpsg/robotassessment/robotassessment.html (assessment)
   www.ojp.usdoj.gov/nij/sciencetech/slides/ImprovedBombRobotProject.pdf (results)

   NIST Performance Metrics for Autonomous Mobile Robots
   www.isd.mel.nist.gov/projects/USAR/

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation