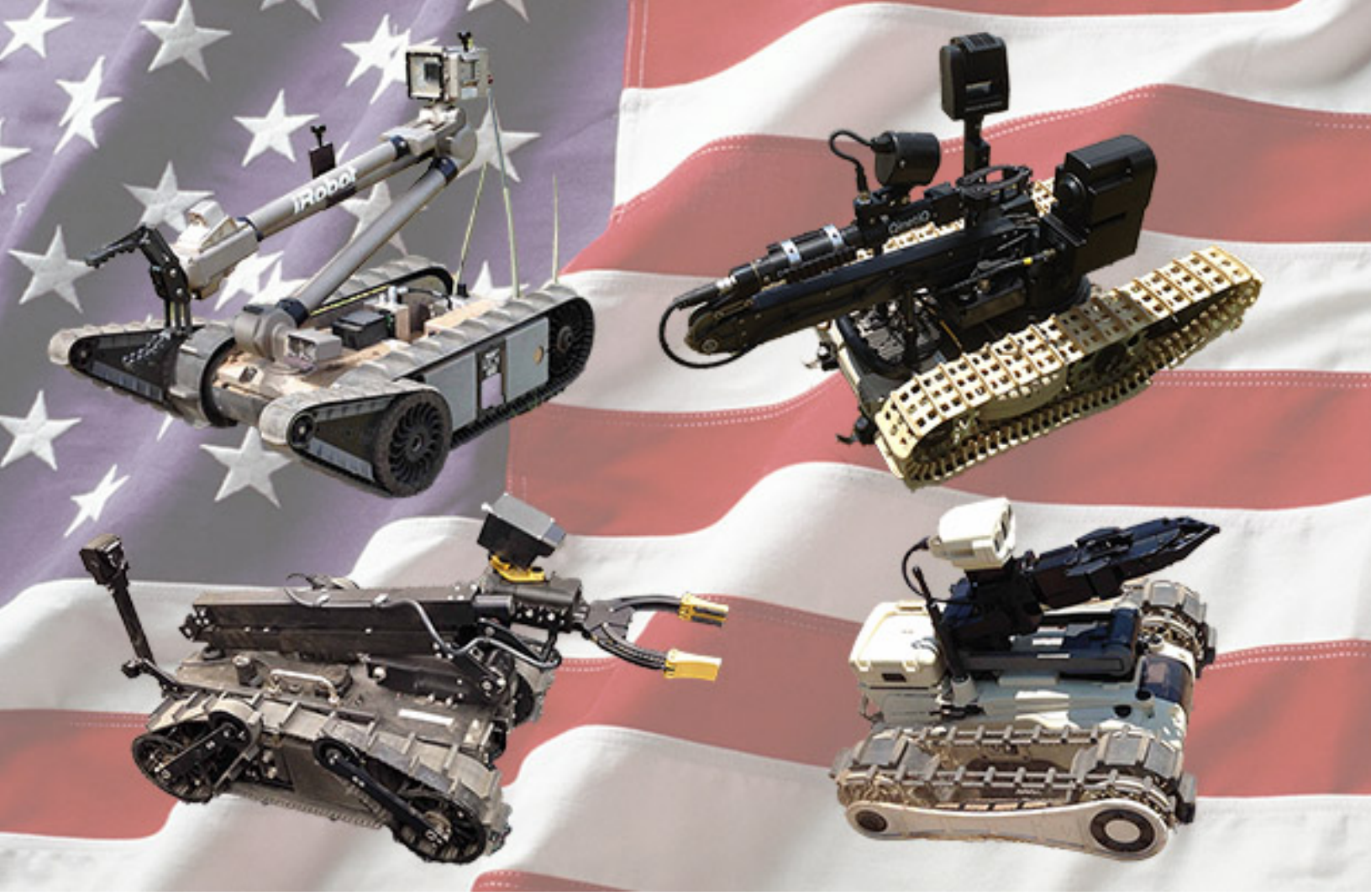


System Assessment and Validation for Emergency Responders (SAVER)

Small Platform Tactical Robots Assessment Report

October 2014

Homeland Security
Science and Technology

U.S. Department of Homeland Security
SAVER
System Assessment and Validation for Emergency Responders

Prepared by Space and Naval Warfare Systems Center Atlantic

The *Small Platform Tactical Robots Assessment Report* was funded under Interagency Agreement No. HSHQPM-13-X-00024 from the U.S. Department of Homeland Security, Science and Technology Directorate.

The cover photo and images included herein were provided by the Space and Naval Warfare Systems Center Atlantic.

FOREWORD

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) Program to assist emergency responders making procurement decisions. Located within the Science and Technology Directorate (S&T) of DHS, the SAVER Program conducts objective assessments and validations on commercially available equipment and systems and develops knowledge products that provide relevant equipment information to the emergency responder community. The SAVER Program mission includes:

- Conducting impartial, practitioner-relevant, operationally oriented assessments and validations of emergency response equipment; and
- Providing information, in the form of knowledge products, that enables decision-makers and responders to better select, procure, use, and maintain emergency response equipment.

SAVER Program knowledge products provide information on equipment that falls under the categories listed in the DHS Authorized Equipment List (AEL), focusing primarily on two main questions for the responder community: "What equipment is available?" and "How does it perform?" These knowledge products are shared nationally with the responder community, providing a life- and cost-saving asset to DHS, as well as to Federal, state, and local responders.

The SAVER Program is supported by a network of Technical Agents who perform assessment and validation activities. As a SAVER Program Technical Agent, the Space and Naval Warfare Systems Center (SPAWARSYSCEN) Atlantic has been tasked to provide expertise and analysis on key subject areas, including communications, sensors, security, weapon detection, and surveillance, among others. In support of this tasking, SPAWARSYSCEN Atlantic developed this report to provide emergency responders with information obtained from an operationally oriented assessment of small platform tactical robots, which fall under AEL reference number 03OE-07-ROBT titled Robots.

Visit the SAVER website on First Responder.gov (http://www.firstresponder.gov/SAVER) for more information on the SAVER Program or to view additional reports on small platform tactical robots or other technologies.

POINTS OF CONTACT

SAVER Program
U.S. Department of Homeland Security
Science and Technology Directorate
FRG Stop 0203
245 Murray Lane
Washington, DC 20528-0215

E-mail: saver@hq.dhs.gov
Website: http://www.firstresponder.gov/SAVER

Space and Naval Warfare Systems Center Atlantic
Advanced Technology and Assessments Branch
P.O. Box 190022
North Charleston, SC 29419-9022

E-mail: ssc_lant_saver_program.fcm@navy.mil

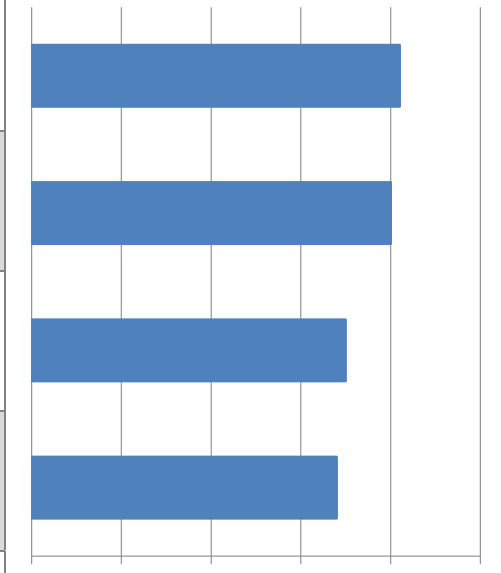
TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

In June 2014, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted an operationally oriented assessment of small platform tactical robots. Four small platform tactical robots were assessed by emergency responders. The criteria and scenarios used in this assessment were derived from the results of a focus group of emergency responders with experience using small platform tactical robots. The assessment addressed 20 evaluation criteria in four SAVER categories: Capability, Deployability, Maintainability, and Usability. The overall results of the assessment are highlighted in the following table.

Product	Overall Score	Overall	Capability	Deployability	Usability	Maintainability
ICOR Technology Inc. Mini-CALIBER		**4.1**	4.1	3.8	4.0	4.5
iRobot Corporation 510 PackBot		**4.0**	4.2	3.8	3.7	3.9
QinetiQ North America Inc. Dragon Runner 20 (DR-20) Small Unmanned Ground Vehicle (SUGV)		**3.5**	3.4	3.5	3.7	3.6
Roboteam North America MTGR (Micro Tactical Ground Robot)		**3.4**	2.9	3.8	3.5	3.9

1. INTRODUCTION

In June 2014, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted an operationally oriented assessment of small platform tactical robots. The purpose of this assessment was to obtain information on small platform tactical robots that will be useful in making operational and procurement decisions. The activities associated with this assessment were based on recommendations from a focus group of emergency responders with experience using small platform tactical robots.

1.1 Evaluator Information

Six emergency responders from various jurisdictions and with at least 4 years of experience using small platform tactical robots were selected to be evaluators for the assessment. Evaluator information is listed in Table 1-1. Prior to the assessment, evaluators signed a nondisclosure agreement, conflict of interest statement, and photo release form.

Table 1-1. Evaluator Information

Evaluator	Years	State
Law Enforcement, Patrol/Bomb Squad	20+	NC
Law Enforcement, Bomb Squad	20+	SC
Law Enforcement, SWAT Team	20+	TX
Law Enforcement, SWAT Team	20+	VA
Law Enforcement, Bomb Squad	16–20	FL
Law Enforcement, Community Response Team	11–15	NC

1.2 Assessment Products

Four products were selected for the assessment based on market research and the focus group's recommendations. Final selection was based on how well each product met the product selection criteria identified by the focus group and listed in Table 1-2.

Table 1-2. Product Selection Criteria

Product Selection Criteria	Description
Attachment Arm	A camera and/or articulating arm should come standard or be available as an accessory
Range	Operational range of at least 300 meters (984 feet)
Number of Cameras	A minimum of three cameras

The products selected for assessment met all product selection criteria.

Table 1-3 presents the products that were assessed.

Table 1-3. Assessed Products

Vendor	Product	Product Image
ICOR Technology Inc.	Mini-CALIBER	
iRobot Corporation	510 PackBot	
QinetiQ North America Inc.	Dragon Runner 20 (DR-20) Small Unmanned Ground Vehicle (SUGV)	
Roboteam North America	MTGR (Micro Tactical Ground Robot)	

2. EVALUATION CRITERIA

The SAVER Program assesses products based on criteria in five established categories:

- **Affordability** groups criteria related to the total cost of ownership over the life of the product. This includes purchase price, training costs, warranty costs, recurring costs, and maintenance costs;
- **Capability** groups criteria related to product features or functions needed to perform one or more responder relevant tasks;
- **Deployability** groups criteria related to preparing to use the product, including transport, setup, training, and operational/deployment restrictions;
- **Maintainability** groups criteria related to the routine maintenance and minor repairs performed by responders, as well as included warranty terms, duration, and coverage; and
- **Usability** groups criteria related to ergonomics and the relative ease of use when performing one or more responder relevant tasks.

The focus group of emergency responders met in November 2013 and identified 20 evaluation criteria within four SAVER categories: Capability, Deployability, Maintainability, and Usability. They assigned a weight for each criterion's level of importance on a scale of 1 to 5, with 1 being

somewhat important and 5 being of utmost importance. The SAVER categories were assigned a percentage to represent each category's importance relative to the other categories. The focus group discussed the Affordability category but did not identify any evaluation criteria for that category.

Products were assessed against 20 evaluation criteria. Table 2-1 presents the evaluation criteria and their associated weights as well as the percentages assigned to the SAVER categories. Refer to Appendix A for evaluation criteria definitions.

Table 2-1. Evaluation Criteria

SAVER CATEGORIES			
Capability	**Deployability**	**Usability**	**Maintainability**
Overall Weight 40%	Overall Weight 25%	Overall Weight 25%	Overall Weight 10%
Evaluation Criteria			
Mobility Weight: 5	**Range** Weight: 5	**Remote Control** Weight: 5	**Warranty** Weight: 4
Cameras Weight: 5	**Durability** Weight: 5	**Video Quality** Weight: 5	**Maintenance** Weight: 4
Audio Communication Weight: 4	**Ease of Setup** Weight: 4	**Audio Quality** Weight: 4	**Technical Support** Weight: 4
Arm Functionality Weight: 4	**Portability** Weight: 4	**User Manual** Weight: 3	
Power Sources Weight: 4	**Training** Weight: 4		
Versatility Weight: 4	**Covertness** Weight: 2		
Remote Monitoring Weight: 1			

3. ASSESSMENT METHODOLOGY

The products were assessed over five days. On the first day of the assessment, a subject matter expert (SME) and facilitators presented a safety briefing and an overview of the assessment process, procedures, and schedule to the evaluators. Each product was then assessed in two phases: (1) specification assessment and (2) operational assessment.

3.1 Phase I/Specification Assessment

During the specification assessment, evaluators assessed each product based on vendor-provided information and specifications. Product information was confirmed by vendors prior to the assessment.

3.2 Phase II/Operational Assessment

During the operational assessment, evaluators assessed each product based on their hands-on experience using the product after becoming familiar with its proper use, capabilities, and features. During product familiarization, each evaluator had 30 minutes to operate the robot and perform the following tasks, all of which were also performed as a group during the operational assessment:

- Use the robot to turn a doorknob;
- Use the robot to pick up and carry a hard-sided case;
- Use the robot's one- or two-way audio communications (if equipped);
- Navigate stairs with the robot; and
- Switch between camera views on the robot.

The vendors, SME, and facilitators assisted the evaluators with product familiarization, and evaluators had access to the reference material included with each product. The products were assessed in two scenarios: (1) setup and (2) hostage/barricade. Evaluators spent one day with each product and completed the assessment worksheets on the day of the assessment.

3.2.1 Setup Scenario

During the setup scenario, evaluators provided ratings and comments on the user manual criterion since this material was reviewed during familiarization. Evaluators then worked as a group to assemble the robot for deployment, which included removing the batteries from the charger and installing them in the robot (Figure 3-1) and the command and control unit (CCU).

Next, they powered on the robot and CCU, readying the unit for deployment. Evaluators also inspected the location of the cameras on the robot and changed between camera view(s) on the CCU.

Figure 3-1. Robot Battery Installation

They also used the zoom capabilities to view a sign and a map inside a room, as seen in Figure 3-2.

The lights in a room were turned off so evaluators could view the CCU in a darkened room and note the display brightness in low-light conditions and whether it automatically adjusted or needed to be adjusted manually. Finally, the evaluators inspected the robot and CCU for durability.

Figure 3-2. Viewing an Image of a Map in a Room on a CCU

3.2.2 Hostage/Barricade Scenario

During the hostage/barricade scenario, evaluators assessed portability by carrying the assembled robot and CCU to a designated location 50 feet away and then returned it to their starting point, as seen in Figure 3-3. Then, the SME drove the robot at top speed toward a designated location 300 meters away so evaluators could assess range. Next, while wearing gloves, each evaluator drove the robot for 3 minutes on various terrains (e.g., sand, grass, gravel, and concrete) while other evaluators watched to assess the robot's mobility.

Figure 3-3. Assessing Portability

After all evaluators had the opportunity to drive the robot for 3 minutes, they were split into two groups. One group followed the robot as the other group drove it to a designated location approximately 100 feet away. The two groups conversed with each other over the robot's two-way communications (if equipped) for approximately 15 seconds. The group at the robot noted the audio quality and the group at the CCU noted the ease of operating the robot, the quality of the audio and video, and if there was any lag or delay in the video transmission. Then, the two groups switched and repeated this part of the scenario.

Next, one of the groups followed the robot while the other stayed at the CCU and attempted to use the robot's articulating arm to open a doorknob and pick up and drop a small hard-sided case, as seen in Figure 3-4. Then they drove the robot inside the building to a dark room where the white light and IR lights were used so the group at the CCU could assess video quality in low-light conditions. The group at the robot followed the robot into the darkened room to assess covertness. The group at the CCU then drove the robot up a flight of stairs and entered a room while the group at the robot followed. The two groups conversed with each other over the robot's two-way communications for approximately 15 seconds while a radio played in the room with the robot.

Figure 3-4. Manipulating Doorknob and Carrying a Hard-Sided Case

Next, the group at the CCU adjusted the robot's cameras to look on the top of tables and under chairs while navigating the robot over clothing placed on the ground and around furniture. At the end of the scenario, evaluators at the robot tipped it over on its side and the group at the CCU attempted to right it using the controls on the CCU. Finally, the two groups switched and repeated this part of the scenario.

3.3 Data Gathering and Analysis

Each evaluator was issued an assessment workbook that contained vendor-provided information and specifications, assessment procedures, and worksheets for recording criteria ratings and comments. Evaluators used the following 1 to 5 scale to rate each product:

1. *Meets none* of my expectations for this criterion;
2. *Meets some* of my expectations for this criterion;
3. *Meets most* of my expectations for this criterion;
4. *Meets all* of my expectations for this criterion; and
5. *Exceeds* my expectations for this criterion.

Criteria that were rated multiple times throughout the assessment were assigned final overall ratings by the evaluators. Facilitators captured advantages and disadvantages for the assessed products as well as general comments on the small platform tactical robots assessment and the assessment process. Once assessment activities were completed, evaluators had an opportunity to review their criteria ratings and comments for all products and make adjustments as necessary.

At the conclusion of the assessment activities, an overall assessment score, as well as category scores and criteria scores, were calculated for each product using the formulas referenced in Appendix B. In addition, evaluator comments for each product were reviewed and summarized for this assessment report.

4. ASSESSMENT RESULTS

Overall scores for the assessed products ranged from 3.4 to 4.1. Table 4-1 presents the overall assessment score and category scores for each product. Products are listed in order from highest to lowest overall assessment score throughout this section. Calculation of the overall score uses the raw scores for each category, prior to rounding.

Table 4-1. Assessment Results

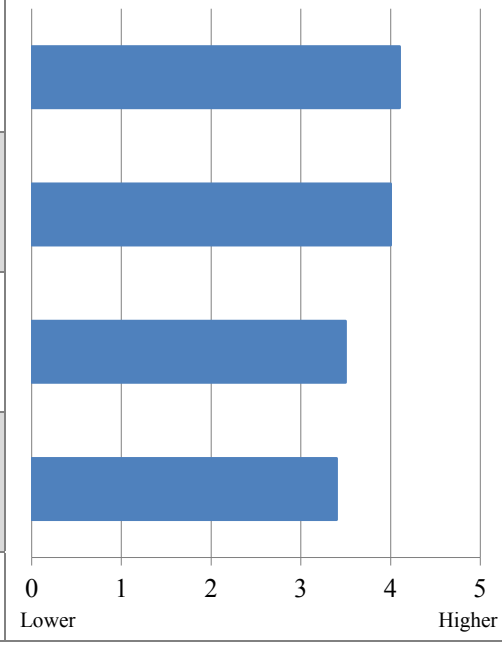
Product	Overall Score	Overall	Capability	Deployability	Usability	Maintainability
ICOR Technology Inc. Mini-CALIBER		**4.1**	4.1	3.8	4.0	4.5
iRobot Corporation 510 PackBot		**4.0**	4.2	3.8	3.7	3.9
QinetiQ North America Inc. Dragon Runner 20 (DR-20) Small Unmanned Ground Vehicle (SUGV)		**3.5**	3.4	3.5	3.7	3.6
Roboteam North America MTGR (Micro Tactical Ground Robot)		**3.4**	2.9	3.8	3.5	3.9

Table 4-2 presents the criteria ratings for each product. The ratings are graphically represented by colored and shaded circles. A green, fully shaded circle represents the highest rating. Refer to Appendix A for evaluation criteria definitions. Evaluators agreed that all four robots offered optional accessories that were relevant and functional for most operations (Versatility). In addition, all of the robots produced minimal noise while operating and the IR lights on the robots were barely visible (Covertness).

Table 4-2. Criteria Ratings

KEY Lowest Rating → Highest Rating ○ ◔ ◑ ◕ ●				

Category	Evaluation Criteria	Mini-CALIBER	510 PackBot	DR-20 SUGV	MTGR
Capability	Mobility	●	●	◑	◑
	Cameras	◕	◕	◕	◑
	Audio Communication	◕	◕	◕	○
	Arm Functionality	◕	◕	◔	◔
	Power Sources	◕	●	◕	◕
	Versatility	◕	◕	◕	◕
	Remote Monitoring	◕	◑	◑	◑
Deployability	Range	◕	◕	◑	◕
	Durability	◕	◕	◔	◕
	Ease of Setup	●	◕	◕	◑
	Portability	◕	◑	◕	◕
	Training	◑	◑	◕	◕
	Covertness	◕	◕	◕	◕
Usability	Remote Control	◕	◕	◕	◑
	Video Quality	◕	◕	◑	◕
	Audio Quality	◕	◑	◕	Not Assessed[1]
	User Manual	●	◕	◕	◕
Maintainability	Warranty	●	◕	◕	◕
	Maintenance	◕	◕	◕	◕
	Technical Support	●	◕	◑	●

[1]The MTGR did not feature an audio communication capability.

Table 4-3 presents vendor-provided key specifications for the assessed products. All robots were powered by non-proprietary rechargeable batteries and featured color cameras with auto-focus. All had sealed housings resistant to impact and water, although none were intrinsically safe. User manuals for the robots were available online and in hard copy upon request. All vendors offered technical support for the life of the products and training that could be held at either the vendor's location or another location of the purchaser's choice.

Table 4-3. Key Specifications

Key Specification	Mini-CALIBER	510 Packbot	DR-20 SUGV	MTGR
Cost as assessed	$37,000	$115,000	$75,000	$48,000
Warranty Duration	24 months	12 months	12 months	12 months
Extended Warranty Available	✓	✓	✓	✓
Camera Locations and Specifications	Articulating arm (PTZ), 720x480 resolution, 1.5 lux, 10x optical zoom	Articulating arm (PTZ), 768x494 resolution, 1.4 lux, 12x optical zoom[1]	Articulating arm (PTZ) 640x480 resolution, 1.5 lux, 40x optical zoom	Articulating arm (PTZ), 720x480 resolution, 0.01 lux, 10x optical zoom
	Gripper, 640x480 resolution	Upper gripper, 640x480 resolution, 0.5 lux	Gripper, 640x480 resolution, 0.2 lux	Gripper, 720x480 resolution, 0.01 lux
	Front, 976x582 resolution	Lower gripper, 640x480 resolution, 0.5 lux	Front, 640x480 resolution, 0.2 lux	Front, 720x480 resolution, 0.01 lux
	Rear, 976x582 resolution	Front turret, 640x480 resolution, 0.5 lux	Rear, 640x480 resolution, 0.2 lux	Rear, 720x480 resolution, 0.01 lux
	Mast, 1024x768 resolution, 0.5 lux		Left side, 640x480 resolution, 0.2 lux	Left side, 720x480 resolution, 0.01 lux
			Right side, 640x480 resolution, 0.2 lux	Right side, 720x480 resolution, 0.01 lux
				Front (PTZ) , 720x480 resolution, 0.01 lux, 6x optical zoom
CCU Screen Size	5.8 inches	15.1 inches	6.5 inches	7.0 inches
Number of Batteries (robot)	2	1 to 4	1	1
Maximum Battery Runtime (robot)	5 hours	8 hours	4 hours	4 hours
Battery Charge Time	4 hours	3 hours	4 hours	3 hours

Key Specification	Mini-CALIBER	510 Packbot	DR-20 SUGV	MTGR
Batteries Charged Simultaneously	2	3	2	2
Hot Swappable Batteries		✓		
Audio Communication	2-way	2-way	2-way	None
Additional Attachment Options	Firing system, shock tube initiator, secondary handheld LCD screen	Thermal imaging camera, various disrupter mounts, HazMat sensors, plus a variety of accessories	Thermal imaging camera, disrupter mounts	Range extender, directional antenna, Glenair® connector to add a variety of accessories to the Picatinny rails
GPS Module Available		✓		✓
Remote Video Monitoring Methods	RCA output, 2.4 GHz analog	Contact vendor for more information	Contact vendor for more information	Contact vendor for more information
Secure Audio/Video Feed	✓	✓		✓
Training Included			✓	✓
Duration of Training	Varies	1, 3, or 5 days	1 day	Varies
Technical Support Hours	24/7	Monday through Friday, 8:00 a.m. to 8:00 p.m. Eastern Time	Monday through Friday, 7:30 a.m. to 5:00 p.m. Eastern Time	24/7
Technical Support Contact Methods	E-mail, phone	E-Mail, phone, live chat	E-mail, phone	E-mail, phone

Notes:
[1]12x optical zoom, 26x digital zoom
✓—product is equipped with corresponding feature
CCU—command and control unit
PTZ—pan-tilt-zoom

4.1 ICOR® Technology Inc. Mini-CALIBER®

The Mini-CALIBER (Figure 4-1) received an overall assessment score of 4.1. As assessed, the Mini-CALIBER cost $37,000 and included front and rear wide-angle drive cameras; a pan-tilt-zoom (PTZ) camera; a gripper camera; a mast camera; a CCU; front and rear articulating flippers; and an articulating arm with gripper.

The following sections, broken out by SAVER category, summarize the assessment results.

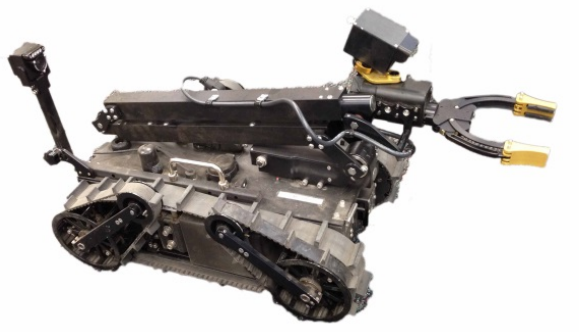


Figure 4-1. Mini-CALIBER

Capability

The Mini-CALIBER received a Capability score of 4.1. The following information is based on evaluator comments:

- The robot was able to traverse various terrains with adequate speed. It climbed the stairs easily and maneuvered around furniture and over objects without issue. The robot was easily righted using the CCU controls;
- The number of cameras and their locations provided good camera views while driving as well as while operating the articulating arm, gripper, and articulating flippers. The elevated mast camera located on the back that points towards the front permitted the operators to see the position of the flippers and articulating arm. In addition, the camera on the gripper provided a helpful perspective to the user when turning the doorknob or picking up the hard-sided case, and it could be positioned for viewing under vehicles due to a quick-release camera mount on the PTZ camera. A higher zoom capability on the PTZ camera is preferred; and
- The grippers on the articulating arm were strong enough to open doors and carry the hard-sided case, and the rubber inserts prevented slipping when gripping an object. The articulating arm's range of motion was excellent and could easily scan above tables and below chairs. In addition, the gripper was positioned on a wrist that could rotate, pan, and tilt, which made small adjustments to the gripper position easier since the entire arm did not have to be moved.

Deployability

The Mini-CALIBER received a Deployability score of 3.8. The following information is based on evaluator comments:

- The operational range of the robot was good; it remained responsive to controls and no degradation of video or audio was experienced, even at 300 meters;

- The robot appeared to be rugged because the tracks contained thick composite plastic, the antennas were low profile, and the housing was comprised of alloy. In addition, the mast camera that projects from the body would automatically fold into stow position when the robot was flipped. The CCU (Figure 4-2) appears to be durable because it consists of mostly push buttons; however, it features a joystick that could be prone to breakage and it did not have any rubber bumpers;

Figure 4-2. Mini-CALIBER CCU

- The robot and CCU were very easy to set up. Once batteries are installed in the robot, the CCU and robot can be powered on and are ready to go with virtually no delay for booting up. In addition, installing the batteries was easy due to latches on the compartment that did not require tools to open. The CCU was easy to configure and only required the user to turn it on; and
- The size and weight of the robot and CCU were acceptable; both could be carried by one person for a short period of time. The robot featured two handles and the CCU had a strap, which aided in portability.

Usability

The Mini-CALIBER received a Usability score of 4.0. The following information is based on evaluator comments:

- The robot's CCU was portable, self-contained, and user friendly with a 5.8-inch screen that could easily be seen in low light and direct sunlight. It was intuitive; every button had a single function, LEDs highlighted the selected mode, and the LCD displayed the part of the robot being manipulated. Raised buttons and the joystick allowed for easy operation while wearing gloves. Though the screen size was adequate, the graphics were small, making it difficult to see some things on the display. In addition, there was no graphical orientation display to show the robot's position and only one camera view could be viewed at a time;
- The video quality was good in all lighting conditions. Both drive cameras featured IR lights that provided excellent images in the dark room. The transmitted video was clear and motion in the video was smooth;
- The audio quality at both the robot and CCU was loud and clear and transmitted without interruption. The push-to-talk (PTT) feature prevented feedback from occurring. Although the radio inside and wind outside could be heard over the audio transmission, neither interfered with being able to hear the conversation; and
- The robot came with a color copy of the user manual, which was comprehensive and easy to understand. Additionally, a tablet computer preloaded with an electronic version of the user manual, as well as videos on maintenance, troubleshooting, and basic operations, was included and very helpful.

Maintainability

The Mini-CALIBER received a Maintainability score of 4.5. The following information is based on evaluator comments:

- An electronic tablet is included with purchase. The tablet is preloaded with the user manual and videos on maintenance and operation;
- The 2-year warranty exceeds industry standards; and
- Technical support is available 24/7, which exceeds industry standards.

4.2 iRobot® Corporation 510 PackBot®

The 510 PackBot (Figure 4-3) received an overall assessment score of 4.0. As assessed, the 510 PackBot cost $115,000 and included a front turret camera; upper and lower gripper cameras; a PTZ camera; a CCU with laptop; front articulating flippers; and an articulating arm with gripper.

The following sections, broken out by SAVER category, summarize the assessment results.

Figure 4-3. 510 PackBot

Capability

The 510 PackBot received a Capability score of 4.2. The following information is based on evaluator comments:

- The robot traversed various terrains, including sand, at excellent speed without hesitation. It climbed the stairs easily and maneuvered around furniture and over objects without issue. It could be righted automatically by simply choosing the self-righting pose on the CCU;
- The number of cameras and their locations provided sufficient camera views, although a dedicated rear drive camera is preferred. There were preset modes for the PTZ camera, including an auto-track mode that followed the gripper, as well as a drive backwards mode that automatically positioned the PTZ camera for driving backwards. The optical zoom capability of the PTZ camera met expectations; and
- The grippers on the articulating arm were strong enough to open doors and carry the hard-sided case. The articulating arm's range of motion was good with an exceptional viewing height that could easily scan above tables and below chairs.

Deployability

The 510 PackBot received a Deployability score of 3.8. The following information is based on evaluator comments:

- The operational range of the robot was good; it remained responsive to controls and no degradation of video or audio was experienced, even at 300 meters;

- The robot appears to be very rugged. It featured flexible antennas and nothing that appeared fragile projected from robot. In addition, it featured large treads all around to absorb shock. The robot took a few bumps down the stairs and continued functioning. The CCU (Figure 4-4) is comprised of a laptop and controller that appear to be very rugged. The laptop is a Panasonic Toughbook® that featured rubber around all corners, a rubberized mat over the keys to keep moisture out, and covered ports. The game-style controller continued to function properly after being accidentally dropped;

Figure 4-4. 510 PackBot CCU

- Set up of the robot and CCU was not a complicated process, although the boot-up time for the robot and configuring the CCU to work with the robot took a little time. A screwdriver is required to access the battery compartment, which is not preferred; and
- The robot was heavy and the CCU was a bit cumbersome since it was comprised of a laptop and a controller. Two people were required to carry the robot and CCU. In addition, the robot featured only one strap near the back; an additional strap on the front would have been helpful due to the weight of the robot.

Usability

The 510 PackBot received a Usability score of 3.7. The following information is based on evaluator comments:

- The robot's CCU with laptop was user friendly, featuring an adequately-sized 15.1-inch screen that could easily be seen in low and normal lighting conditions. Two cameras could be displayed at once, which was preferred. The CCU was intuitive to operate with a Sony PlayStation® 2 controller, onscreen help menus, and preset poses. Wearing gloves did not hinder operation. The graphical orientation on the display to show the robot's position when out of view was helpful. Visibility of the screen was a little difficult in direct sunlight; however, it was helpful that the brightness could be manually adjusted;
- The video quality was good in most lighting conditions, although it was a little difficult to see with only the IR lights on in the dark room. The transmitted video was clear and motion in the video was smooth. Only minor pixilation was experienced at times;
- The audio volume was difficult to figure out due to feedback and echoing that would occur when the microphone picked up audio from the speaker. If the volume was turned down enough to prevent the feedback and echoing from occurring, it was difficult to hear the conversation. A PTT feature would likely resolve this issue. Wind caused a little static noise over the audio transmission while outside. The radio did not interfere with being able to hear the conversation indoors; and

- The robot came with a comprehensive user manual as well as an instructional DVD and quick-reference guide.

Maintainability

The 510 PackBot received a Maintainability score of 3.9. The following information is based on evaluator comments:

- Detailed maintenance instructions were provided; and
- Technical support is only available during business hours, which does not meet expectations.

4.3 QinetiQ® North America Inc. Dragon Runner™ 20 (DR-20) Small Unmanned Ground Vehicle (SUGV)

The DR-20 SUGV (Figure 4-5) received an overall assessment score of 3.5. As assessed, the DR-20 SUGV cost $75,000 and included front and rear drive cameras; left and right side cameras; a gripper camera; a PTZ camera; a CCU; front articulating flippers; and an articulating arm with gripper.

The following sections, broken out by SAVER category, summarize the assessment results.

Figure 4-5. DR-20 SUGV

Capability

The DR-20 SUGV received a Capability score of 3.4. The following information is based on evaluator comments:

- The robot performed fairly well traversing various terrains with sufficient speed, with only minimal difficulty in the sand. The articulating arm had to be extended when climbing stairs to shift the center of gravity. The robot could not be righted after it was flipped over; this may have been due to the malfunctioning articulating arm;
- The number of cameras and their locations provided sufficient camera views. Having four cameras on the body pointing front, back, and on both sides provided for great situational awareness. It featured a gripper camera built into the wrist that turned 360 degrees, which allowed for under vehicle searches should the need arise. The PTZ was at a fixed height and the articulating arm had to be moved to tilt the gripper camera; it did not move very smoothly when making small changes to the arm's position to adjust the camera. In addition, the camera view was very shaky while driving the robot. A higher zoom capability on the PTZ camera is preferred; and
- The robot's articulating arm malfunctioned during the assessment, which inhibited its ability to turn doorknobs and carry the hard-sided case up stairs. Although the grip was strong, the gripper lacked a rubber lining, which would have aided with grip. That, along with the malfunctioning arm, contributed to the robot not being able to turn the doorknob. In addition, it had difficulty carrying the hard-sided case up the stairs due to the shoulder joint slipping, causing the arm to rotate to the side. The

robot could easily scan above tables but looking under objects could not be assessed due to the issues with the arm malfunctioning.

Deployability

The DR-20 SUGV received a Deployability score of 3.5. The following information is based on evaluator comments:

- The operational range of the robot was good; however, the robot became less responsive to controls and degradation of video/audio was experienced at approximately 250 meters. The robot maintained most functionality at 300 meters;
- The robot did not appear to be very rugged. Due to a slipping clutch, the articulating arm slowly lost functionality during the assessment and the cables connecting the audio transmitter to the robot were ripped out during operation when the transmitter slid off the Picatinny rail. The CCU appeared to be rugged and sealed;
- The robot and CCU were very easy to set up. Once batteries are installed, the CCU and robot can be powered on and are ready to go with virtually no delay for booting up; and
- The size and weight of the robot and CCU were acceptable; both could be easily carried by one person for a short period. The robot's handle was well placed and sufficient for carrying the lightweight robot. The CCU was incorporated into a backpack, which permitted operators to use both hands to carry the robot if necessary.

Usability

The DR-20 SUGV received a Usability score of 3.7. The following information is based on evaluator comments:

- The robot's CCU (Figure 4-6) had a very bright and clear 6.5-inch screen that suffered only minimal fading in direct sunlight. Users can manually adjust the brightness as well as select to view either one or four cameras at a time, which exceeded expectations. All the controls were labeled, assisting in operation. Raised buttons and the joysticks permitted easy operation while wearing gloves. The screen size was adequate for a handheld unit, but a larger screen would be nice. There was no graphical orientation display to show the robot's position;

Figure 4-6. DR-20 SUGV CCU

- The video quality was clear in normal lighting conditions. The only camera with an IR light source was the drive camera, which provided very clear images in the dark room. The camera on the articulating arm did not have its own IR source but was sensitive to the drive camera's IR light. The side cameras did not have any visibility in the dark room. The video transmission was good, although the camera image was jerky when panning and zooming;

- The audio quality at both the robot and CCU was loud and clear and transmitted without interruption. The PTT feature prevented feedback from occurring. The audio communications stopped functioning when the transmitter slid off the Picatinny rail and the wiring was damaged. Consequently, comments were not able to be collected regarding whether wind or radio noise interfered with hearing the conversation; and
- The robot did not come with a hard copy of the user manual; however, the user manual was provided in electronic format on a CD-ROM and featured many thorough and detailed photographs to explain functions and features.

Maintainability

The DR-20 SUGV received a Maintainability score of 3.6. The following information is based on evaluator comments:

- No special tools are required to perform general maintenance; however, minimal maintenance information was provided; and
- Technical support is only available during business hours, which does not meet expectations.

4.4 Roboteam™ North America MTGR™ (Micro Tactical Ground Robot)

The MTGR (Figure 4-7) received an overall assessment score of 3.4. As assessed, the MTGR cost $48,000 and included front and rear drive cameras; left and right side cameras; a gripper camera; a second front camera with zoom; a PTZ camera; a CCU; front articulating flippers; and an articulating arm with gripper.

The following sections, broken out by SAVER category, summarize the assessment results.

Figure 4-7. MTGR

Capability

The MTGR received a Capability score of 2.9. The following information is based on evaluator comments:

- Overall, the robot performed well traversing various terrains, such as sand, gravel and grass. Its top speed was not particularly fast; however, its maneuverability was good. It had quite a bit of difficulty navigating stairs, and the articulating arm was not long enough to open doors, and it could barely see above table height. Although the robot could be righted by using the CCU controls, it could not be righted every time;
- Most of the cameras provided sufficient camera views; however, the small size of the robot affected the ability of any of the cameras to provide a view over tall objects such as tables. It had seven cameras in total, with four on the body that pointed front, back, and towards either side, providing for great situational awareness. The gripper camera moved with the gripper, which frustrated most of the evaluators, causing them to lose perspective during operation. A higher zoom capability on the PTZ camera is preferred;
- The robot did not have an audio communication capability; and

- The grippers were strong and the robot had no issues carrying the small hard-sided case; however, the arm is too short to reach doorknobs and it had a limited range of motion. It could easily look under objects but was barely tall enough to scan over tables.

Deployability

The MTGR received a Deployability score of 3.8. The following information is based on evaluator comments:

- The operational range of the robot was good; it remained responsive to controls and no degradation of video or audio was experienced, even at 300 meters;
- The robot is made of what appears to be durable plastic without anything projecting from the body; therefore, it appears less likely to break if it tips. The connectors on the robot between the arm and chassis are concealed to protect them from damage. Some issues with the drive motors on the flippers were experienced during the assessment; the drive motors appeared to fail and the robot did not have the strength in the drive to right itself. The CCU has rubber bumpers on each corner and appears to be made of durable materials; however, the multiple cables between the two CCU components appear to be easily damaged, possibly causing malfunctions;
- The robot was easy to set up because no tools were required but it was time consuming. Once the battery was installed, the robot could be powered on simply with a switch and the boot up time was minimal. Battery installation required the user to take off the articulating arm. Removing and reattaching the arm required two cables to be disconnected and reconnected. It is difficult to configure the CCU for deployment because of the amount of time necessary to put in batteries and connect four cables. The storage case does not permit the CCU components to be stowed with the four cables connected. Once the battery was installed, the CCU could be turned on and it booted up relatively quickly; and
- The size and weight of the robot and CCU were acceptable; both could be easily carried by one person for a short period. The robot was lightweight and featured one strap on the back, which was sufficient. The CCU (Figure 4-8) is comprised of two components: a battery pack/transmitter and a controller. It was lightweight and easy to carry since the battery pack/transmitter could be attached to a vest or belt; however, it was slightly cumbersome due to the cables connecting the battery pack/transmitter to the controller.

Figure 4-8. MTGR CCU

Usability

The MTGR received a Usability score of 3.5. The following information is based on evaluator comments:

- The robot's CCU had a really bright and clear 7.0-inch screen that suffered only minimal fading in direct sunlight. The display automatically adjusted brightness to accommodate for lighting conditions and the brightness could also be manually adjusted. It always displays four camera views on the screen at once; this was confusing at times due to the smaller screen size, and the option to view a single camera view if desired was preferred. Although somewhat intuitive to operate, the complexity of the menus and the small graphics require practice. The joysticks were big and the raised hot buttons were large with hard dividers between them, resulting in the controls being easy to operate while wearing gloves. In addition, the touchscreen was responsive while wearing gloves. The graphical orientation on the display to show the robot's position when out of view was helpful;
- The video quality was good in all lighting conditions. There are multiple cameras with an IR light so images provided while in the dark room were very clear. The video transmitted smoothly without issue; and
- The robot included a hard copy user manual, maintenance manual, and quick-start guide that featured many helpful photos and diagrams. It also came with a CD-ROM that featured an electronic version of the user manual.

Maintainability

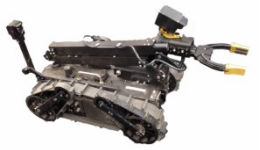
The MTGR received a Maintainability score of 3.9. The following information is based on evaluator comments:

- Technical support is available 24/7, which exceeds industry standards.

5. SUMMARY

Small platform tactical robots are typically used for information gathering when deployed to potentially hazardous incidents. Their use allows law enforcement personnel to maintain a safe distance and still obtain valuable data, such as video and audio. Small platform tactical robots may also facilitate communication between law enforcement and those at the center of the incident. As such, clear audio and video is extremely important. Evaluators preferred systems with well-placed cameras as well as two-way audio. The ability to climb stairs and carry small items was also an important factor. Evaluators also preferred easy-to-swap batteries as well as intuitive and easy to use CCUs. Evaluators noted that it was beneficial that all the products assessed accepted some type of EOD disrupter, were water-resistant or waterproof, had at least a 12-month warranty, were able to remain largely functional at long range (300 meters), had variable drive speeds, and had multiple IR capabilities. Finally, covert operations can be limited due to minimal noise produced by the robots while in operation. The advantages and disadvantages for the assessed products are highlighted in Table 5-1.

Table 5-1. Product Advantages and Disadvantages

Vendor/Product	Advantages	Disadvantages
 ICOR Technology Inc. Mini-CALIBER $37,000 Overall Score: 4.1	• Ease of setup • Very easy to operate, command and control unit (CCU) well laid out • Good speed variance • Well-constructed • Good at climbing stairs • Had front and rear flippers, which aided mobility • User manual in tablet form with short videos on maintenance and operation • 24-month warranty • 24/7 technical support • Overnight parts replacement • Portable, self-contained CCU • Quick-release camera mount to adjust pan-tilt-zoom (PTZ) camera for clearance height for vehicle inspections	• No graphical orientation display to show robot's position • Training is an additional cost • Graphics were small, making it difficult to see some icons on the CCU
 iRobot Corporation 510 PackBot $115,000 Overall Score: 4.0	• Good at climbing stairs • Graphical orientation display to show robot's position • Automatic self-righting • Variety of pre-set poses as well as programmable ones • Sony PlayStation 2 controller • Dual radio systems (2.4 GHz or 4.9 GHz) • Excellent viewing height • Great top speed • Ability to use up to four batteries to increase runtime • HazMat and surveillance platform accessories are available	• Training is an additional cost • Cumbersome CCU; heavy robot • Very slow boot-up time • Feedback during audio communications

Vendor/Product		Advantages	Disadvantages
	QinetiQ North America Inc. Dragon Runner 20 (DR-20) Small Unmanned Ground Vehicle (SUGV)	• CCU and robot were backpack-wearable, which made for great portability • Built-in gripper camera on the articulating arm allowed for under vehicle searches • CCU screen was bright and clear • Push-to-talk audio communication quality was outstanding	• No graphical orientation display to show robot's position • Gripper on articulating arm lacked a rubber lining • Picatinny rail quick-release lever came loose multiple times, which caused the audio transmitter for two-way communication to be dislodged and the wire ripped loose • Clutches slipped in shoulder of arm, making stair climbing as well as use of articulating arm difficult
$75,000	Overall Score: 3.5		
	Roboteam North America MTGR (Micro Tactical Ground Robot)	• 24/7 technical support • Graphical orientation display to show robot's position • Could take arm and base plate off easily without tools for modular use. • Excellent CCU display brightness • Could easily operate touchscreen while wearing gloves	• Short articulating arm made it unable to open doors or see much higher than table top height • Lack of two-way audio communications • Trouble climbing stairs • Cumbersome CCU had four cabled connections • Some of the graphics on the CCU were small, making it difficult to see some icons
$48,000	Overall Score: 3.4		

Emergency responder agencies that consider purchasing small platform tactical robots should carefully research each product's overall capabilities and limitations in relation to their agency's operational needs.

APPENDIX A. EVALUATION CRITERIA DEFINITIONS

The focus group identified 20 evaluation criteria, which are defined as follows.

CAPABILITY

Mobility refers to the ability of the robot to navigate various terrains and impediments such as stairs, furniture, and clothing. Mobility also includes if the robot is capable of self-righting, either automatically or by using the remote control, as well as the speed it can travel.

Cameras refers to the number and types of cameras (e.g., color, black and white) on the robot and includes their location on the robot as well as their resolution, lux rating, magnification, and ability to auto focus.

Audio Communication refers to the robot being capable of one-way or two-way communication.

Arm Functionality refers to the arm on the robot featuring a gripper and/or a camera. If the arm includes a gripper, arm functionality includes how well the gripper works, which may be affected by the gripper strength, extension length, lifting capacity, and range of motion. If the arm includes a camera, arm functionality includes how well the camera can capture the surrounding area as well as the height of the surveillance platform.

Power Sources refers to the number and type of batteries (e.g., commercially available or proprietary) required to power the robot and remote control as well as the battery runtime and charge time. Focus group participants noted the importance of being able to charge multiple batteries at the same time as well as batteries being field-replaceable and easy to change and/or charge without requiring the use of tools.

Versatility refers to the attachments (e.g., articulating arms, cameras) included with purchase, as well as additional attachments available from the vendor for an additional cost.

Remote Monitoring refers to the ability to monitor audio and video remotely (e.g., on a monitor other than the remote control) as well as the technology used to provide remote monitoring (e.g., RF, wired, fiber optics, etc.). Remote monitoring includes a video-out port on the remote control.

DEPLOYABILITY

Range refers to the maximum distance, with and without barriers (i.e., walls, buildings), from which the robot can be controlled and still maintain functionality (i.e., audio/video quality, control of robot).

Durability refers to the overall ruggedness of the robot and remote control, which includes their resistance to water and shock. Focus group participants noted the importance of the robot having a sealed housing as well as the ability to decontaminate it after use in a hazmat environment.

Ease of Setup refers to the amount of time required to prepare the robot for use.

Portability refers to the entire robot system (i.e., carrying cases with all system components) and individual components (i.e., robot and remote control only) featuring shoulder straps or handles and being easily transported to the site of intended use. The size and weight of the entire robot system, robot, and remote control may affect portability.

Training refers to whether training is included with purchase or available for an additional cost, the duration of training provided, as well as the location of the training (e.g., offsite or onsite).

Covertness refers to the covertness of the robot. Covertness may be affected by the type of lights on the robot (e.g., infrared, visible), noise produced by the robot during operation, and the robot's color.

USABILITY

Remote Control refers to the intuitiveness of the remote control as well as its display size. Remote control also includes the ability to view multiple cameras simultaneously (i.e., split-screen) on the display, the visibility of the remote control—including the display—in various lighting conditions, and the remote control being easy to operate while wearing gloves.

Video Quality refers to the clarity and smoothness of the live video transmitted by the robot and received by the remote control.

Audio Quality refers to the clarity and volume of the live audio transmission from the robot to the remote control as well as from the remote control to the robot, if equipped with 2-way communication.

User Manual refers to the usefulness of the information provided in the user manual and/or quick-reference guide as well as the format (e.g., hard copy, electronic copy) and availability (e.g., online, upon request).

MAINTAINABILITY

Warranty refers to how long and comprehensively the system is covered from time of purchase.

Maintenance refers to whether users can self-service the robot and remote control or if company service is required.

Technical Support refers to the duration, availability, and contact methods of technical support.

APPENDIX B. ASSESSMENT SCORING FORMULAS

The overall score for each product was calculated using the product's averaged criterion ratings and category scores. An average rating for each criterion was calculated by summing the evaluators' ratings and dividing the sum by the number of responses. Category scores for each product were calculated by multiplying the average criterion rating by the weight assigned to the criterion by the focus group, resulting in a weighted criterion score. The sum of the weighted criterion scores was then divided by the sum of the weights for each criterion in the category as seen in the formula and example below.

Category Score Formula

$$\frac{\sum\left(Average\,Criterion\,Rating \times Criterion\,Weight\right)}{\sum\left(Criterion\,Weights\right)} = Category\ Score$$

Category Score Example[1]

$$\frac{\left(4.3\times 4\right)+\left(5\times 4\right)+\left(4\times 3\right)+\left(4.5\times 3\right)+\left(4.5\times 3\right)}{4+4+3+3+3} = 4.5$$

To determine the overall assessment score for each product, each category score was multiplied by the percentage assigned to the category by the focus group. The resulting weighted category scores were summed to determine an overall assessment score as seen in the formula and example below.

Overall Score Formula

$$\sum\left(Category\ Score \times Category\ Percentage\right) = Overall\ Assessment\ Score$$

Overall Score Example[1]

Capability		*Usability*		*Affordability*		*Maintainability*		*Deployability*		
$\left(4.0\times 33\%\right)$	+	$\left(4.2\times 27\%\right)$	+	$\left(4.2\times 20\%\right)$	+	$\left(3.8\times 10\%\right)$	+	$\left(4.5\times 10\%\right)$	=	4.1

[1]Examples are for illustration purposes only. Formulas will vary depending on the number of criteria and categories assessed and the criteria and category weights.