ARL-TR-9582 ● SEP 2022

DEVCOM ARL FY22 Industry Autonomy Technology Assessment (IATA) Final Report on Security and Mobility

by Marshal Childers, John Millemaci, Anthony Barnett, Jacob Sepinuck, Christian Ellis, Craig Lennon, and Luis Hernandez

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Marshal Childers, Christian Ellis, Craig Lennon, and Luis Hernandez
DEVCOM Army Research Laboratory

John Millemaci
Energetics Technology Center

Anthony Barnett and Jacob Sepinuck
Reserve Officers' Training Corps, US Army Cadet Command

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
September 2022	Technical Report	18 July – 31 August 2022

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
DEVCOM ARL FY22 Industry Autonomy Technology Assessment (IATA) Final Report on Security and Mobility	
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Marshal Childers, John Millemaci, Anthony Barnett, Jacob Sepinuck, Christian Ellis, Craig Lennon, and Luis Hernandez	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
DEVCOM Army Research Laboratory ATTN: FCDD-RLC-IS Aberdeen Proving Ground, MD 21005	ARL-TR-9582
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

ORCID IDs: Marshal Childers, 0000-0002-8723-6977; Christian Ellis, 0000-0002-0544-8627

14. ABSTRACT

Forces that will conduct missions for extended periods in expeditionary situations require technologies that are mobile, robust, and have sufficient autonomy to increase team effectiveness. The US Army Combat Capabilities Development Command Army Research Laboratory solicited solutions from industry that demonstrate autonomous mobility and autonomous security in operationally relevant scenarios. During July 2022, three companies participated in an evaluation by DEVCOM Army Research Laboratory to assess off-the-shelf capabilities to increase situational awareness by detecting and responding to unknown actors in various scenarios near a named area of interest. This report describes the first Industry Autonomy Technology Assessment with details on the challenges, data and analysis of performance, feedback, and recommendations that can be used by developers and stakeholders to leverage the demonstrated strengths and invest in areas where more capability is required. The results show that current technologies can be used for limited surveillance and reconnaissance tasks, and the level of demonstrated performance warrants further development to increase capability across environments, situations, and mission sets.

15. SUBJECT TERMS

autonomy, robotics, UGV, perception, security, situational awareness, technology assessment, Mechanical Sciences

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Marshal Childers
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER (Include area code)**
Unclassified	Unclassified	Unclassified	UU	46	443-417-3667

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Acknowledgments

The authors thank the following individuals that participated in and supported the Industry Autonomy Technology Assessment (IATA) as technology performers:

- Asylon Robotics: Uzkar Ibrahim, Adam Mohamed, Brent McLaughlin, and Daniel Lombino
- Booz Allen Hamilton: Kelsie Reinaltt, Patrick Ward, Robert Nicholas, Michael Titus, Stephanie Boone-Shaw
- Ghost Robotics and ARES Security: James Laney, James Honicker, Christine Eveland, John Halsema, Blane Schertz, and Martin Rahmani

The authors thank the following organizations that participated in and supported the IATA:

- Air Force Research Laboratory
- DEVCOM ARL
- DEVCOM Armaments Center
- Johns Hopkins Applied Physics Laboratory
- Marine Corps Warfighting Laboratory
- Test Resources Management Center

Executive Summary

During 18–22 July 2022, the US Army Combat Capabilities Development Command Army Research Laboratory, three companies, and numerous attendees from other government organizations gathered at the Robotics Research Collaboration Campus (R2C2) at Aberdeen Proving Ground, Maryland, to demonstrate and evaluate ground robotics technologies with capabilities for protecting operating areas, personnel, and infrastructure in numerous types of environments and situations during its first ever Industry Autonomy Technology Assessment (IATA) event. This event reflects DEVCOM Army Research Laboratory's commitment to collaborate in robotics research with academia, industry, and other government organizations.

The purpose of the IATA is to inform Army modernization efforts through innovation, discovery, demonstration, and experimentation of autonomy technologies and to accelerate the delivery of innovative capabilities to the warfighter. It provides an operationally relevant environment and problem set that enables technology developers to demonstrate new technologies and apply existing technologies in innovative ways. It also provides a means for the government to assess and provide feedback on performance of technologies for known gaps and emerging needs. The primary objective of the IATA is to identify and assess technologies that can accelerate solutions relevant to Army modernization priorities. The IATA presented an environment to examine and understand Army challenges and provide assessment data to participants on how their technologies address the challenges.

It was our intention to expose the technologies from each participating company to three vignette types, with multiple run types associated with each vignette:

- Autonomy for Security: Urbanized Terrain
- Autonomous Mobility
- Autonomy for Security: Vegetated Trail Terrain

A total of three companies demonstrated their ground-based robotic technologies during the event. The companies who participated in the IATA were the following:

1) Asylon Robotics
2) Booz Allen Hamilton
3) Ghost Robotics/ARES Security

Attendees at the event included representatives from Air Force Research Laboratory, DEVCOM Armaments Center, ARL, John Hopkins Applied Physics Laboratory, Marine Corps Warfighting Laboratory, and the Test Resource Management Center. Support for the planning and execution of the IATA event was provided by Energetics Technology Center, Inc through its Partnership Intermediary Agreement with ARL.

This report describes the site, vignettes, and assessment methods and provides feedback on the performance of the included technologies. To allow candid reporting of the performance of the robotic systems and to preclude attribution to a specific company's technology, this report refers to Company A, B, and C, the order of which does not correlate to the order of the participant list in this Executive Summary.

1. Introduction and Purpose

The purpose of the US Army Combat Capabilities Development Command Army Research Laboratory Industry Autonomy Technology Assessment (IATA) was to inform Army modernization efforts through innovation, discovery, demonstration, and experimentation of autonomy autonomous robotics technologies, including legged mobility and automated security. Evaluating the maturity and capability of these technologies accelerates the delivery of such innovative capabilities to the warfighter.

The IATA provided an operationally relevant environment and problem set that enables technology developers to demonstrate new technologies and to apply existing technologies in innovative ways. It also provided a means for the government to assess and provide feedback on performance of technologies for known gaps and emerging needs. The primary objective of the IATA was to identify and assess technologies that can accelerate solutions relevant to Army modernization priorities. The IATA presented an environment to examine and understand Army challenges and provide assessment data to participants on how their technologies address the challenges. The IATA made use of one of DEVCOM Army Research Laboratory's newest assets, the Robotics Research Collaboration Campus (R2C2), at Aberdeen Proving Ground, Maryland.

This report documents the design, execution, and results of the IATA event, and provides conclusions and recommendations. Section 1 introduces the document, citing the purpose of the IATA and an overview of this report. Section 2 describes the demonstration venues, including photographs. Section 3 provides a brief overview of the assessment process and includes the objective of the assessment, the proposed scenarios (with accompanying diagrams and photographs), and the various runs that were planned and executed. Section 4 lists the configurations of the technologies that were demonstrated during the IATA. Section 5 provides analysis of performance for each vignette. Section 6 provides results of the assessments by category, and the conclusions are summarized in Section 7.

2. Facility Description

The R2C2 supports Army research in the areas of robotics, artificial intelligence, autonomy, and human–robot teaming. The facility provides ARL and collaborators with the opportunity to conduct transformational research critical to multi-domain operations and science and technology in the dirt. As a facility with rich terrain features that support mission-relevant scenarios and includes a plethora of engineering facilities, it poses as an ideal location to perform technology assessments.

The site is located on a peninsula and consists of approximately 700 acres of woods, vegetation, shoreline, and infrastructure (Fig. 1). There are semi-improved paths through the vegetation with some cleared paths with undergrowth (Fig. 2). The infrastructure consists of a 600-ft-diameter gravel pad with a Military Operations on Urbanized Terrain (MOUT) configuration, an unmanned ground vehicle (UGV) terrain course (Fig. 3), and various other operations and support buildings.

Fig. 1 R2C2 facility

Fig. 2 Vegetated environment at R2C2

Fig. 3 Configurable MOUT structures (top); UGV terrain course (bottom)

3. Assessment Process

3.1 Objective

The assessment provided an opportunity for each company to demonstrate capabilities that are suited to the scenarios described in the next section. It is understood that the performance achieved was based on the technology configurations that were applied, the scenarios and how they were administered, and the conditions for that day (lighting, temperature, cloud cover). The primary objective of the assessment was to determine if the current state of these technologies meets a minimum viability standard for use. We acknowledge that further research and development work is required to provide the robust solutions that the Army needs, and our desire is that the findings of this assessment will contribute toward that goal. Secondary objectives included the generation of ideas by the performers and attendees on how to leverage the shown capabilities and to identify potential collaborative efforts to build upon them.

3.2 Scenarios

The IATA scenarios consisted of mobility and situational awareness challenges that are relevant to security and protection of personnel and infrastructure. Two scenarios were used to present the challenges: Autonomy for Security and Autonomous Mobility. The Autonomy for Security scenario was conducted in two environments: the first consisting of a limited number of runs in the MOUT area and a more extensive set in the vegetated trail. The Autonomous Mobility assessment was conducted in the various terrains provided by the UGV terrain course and the other three terrain types consisting of tall grass, saplings with undergrowth, and mature woods with undergrowth.

The scenarios were administered in order of difficulty starting with detection of activity in the urbanized environment, followed by mobility on the terrain course, then moving into the vegetated, off-road areas for activity detection and mobility. The extent of scenario attempts was driven by the capabilities of the included technologies. We began with an initial range of detection determined in the relatively benign environment of the gravel pad to ensure that the advertised capability agreed with the planned range of detection in the vegetated trail scenario.

The solicited capabilities for assessment were categorized as Autonomy for Security and Autonomous Mobility. Figure 4 shows the areas where these capabilities were evaluated.

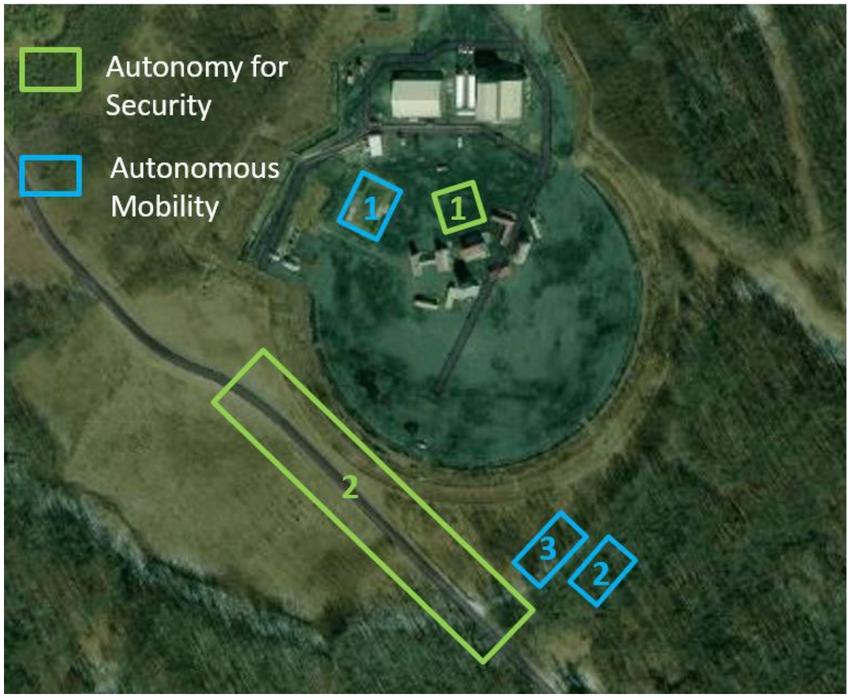

Fig. 4 Location of scenario activities

3.2.1 Autonomy for Security

The Autonomy for Security scenario was conducted in two environments: the first consisting of a limited number of runs in the MOUT area and a more extensive set in the vegetated trail. The overview image in Fig. 5 depicts a view of the MOUT activity with designation of buildings that corresponds to the experimental design provided in the next section. Figure 6 shows the layout for the activity along the vegetated trail and the two photographs in Fig. 7 show the view from the observation post to the area of interest. The image in Fig. 8 indicates the choreography used by the actors.

Fig. 5 View of the autonomy for security activity in the MOUT (urbanized) area

Fig. 6 Autonomy for security scenario in vegetated trail

Fig. 7 Views from observation post to area of interest on vegetated trail

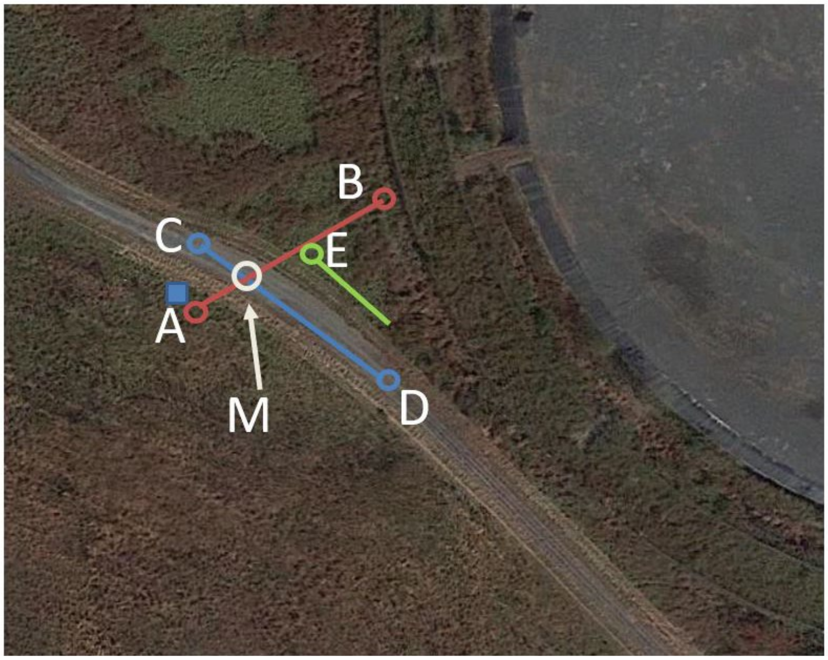

Fig. 8 Choreography of autonomy for security assessment on vegetated trail

3.2.2 Autonomous Mobility

The Autonomous Mobility assessment was conducted in the various terrains provided by the UGV terrain course and the other three terrain types consisting of tall grass, saplings with undergrowth, and mature woods with undergrowth. The location and depiction of the terrain areas are provided in Figs. 3 and 4. Figures 9 and 10 show the terrains available for assessing maneuver in dense vegetation.

Fig. 9 Sapling terrain

Fig. 10 Mature wooded terrain

3.2.3 Data Collection

The experiment proceeded with the use of a schedule of conditions for each activity. The activity in the MOUT area consisted of the conditions shown in Table 1. The technologists were told what activity would take place and they were given the option to set the robot and zoom the onboard sensors to an appropriate depth of view to survey the area. In cases where activity was restricted to a small area (as in the run with a person behind a window) they were permitted to adjust the camera view.

Table 1 Experimental design for autonomy for security in the urbanized environment

Run	Actor	Scenario
1	Single pedestrian	Walk from Bldg. A, behind B, appear between B and C
2	Single pedestrian	Appear from shadow of Bldg. A, enter building B
3	Two pedestrians	Exit from Bldg. B, walk in separate directions
4	Two pedestrians	Stand/move behind window on each floor in Bldg. A
5	Vehicle, single pedestrian	Vehicle appears, pedestrian exits vehicle, walks behind Bldg. B

The assessment in the vegetated trail area consisted of Runs 1, 2, 5, 6, 12, 19, 23, and 24 of the activities listed in Table 2. Selection of which run to include was based on the reported capabilities of the present technologies and on consideration of the perception algorithms used, the available autonomy, and the communications system in use. Figure 8 shows the locations and directions of travel for the activities shown in Table 2.

Table 2 Experimental design for autonomy for security in vegetated trail environment

Run	Actors	Activity
1	Single ped	Slow walk A to B
2	Single ped	Brisk walk A to B
3	Single ped	Slow walk A to M, stop, turn around, walk
4	Single ped	Walk A to M, turn 90°, walk to D
5	Single ped	Walk B to E, turn 90°, walk parallel to road
6	Single ped	Walk to M, crouch
7	Single ped	Walk with object A to M, release object, walk to B
8	Single ped	Walk from C to D
9	Single ped	Walk behind vehicle A to B
10	Single ped	Walk behind vehicle A to M, turn 180°, walk
11	Dual pedestrians	Ped1 and Ped2 A to M; One carries object (cooler)
12	Dual pedestrians	Ped1 and Ped2 A to M; Ped1 to B Ped2 to A
13	Dual pedestrians	Ped1 A to M; Ped2 B to M
14	Dual pedestrians	Ped1 A to B; Ped2 C to D
15	Vehicle	Drive from C to D
16	Vehicle	Drive A to M, stop
17	Vehicle	Drive C to M, turn toward B
18	Vehicle	Drive C to M; turn around, drive back
19	Vehicle and ped	Vehicle C to M, Ped1 exits and walk to B
20	Vehicle and ped	Vehicle C to M, Ped1 A to M, enter vehicle, vehicle M to D
21	Vehicle and ped	Orthogonal path, stop, Ped1 exits
22	Vehicle and ped	Vehicle C to M, Ped1 exits, Ped1 and vehicle to D
23	Vehicle and ped	Vehicle C to M, Ped1 and Ped2 A to M, Ped1 enters vehicle, Vehicle M to D
24	Vehicle and ped	Vehicle C to M, driver exits and walks to B, Ped1 walks A to M, enters vehicle

The assessment for mobility consisted of the conditions shown in Table 3. The length of the UGV terrain course was 300 ft and we established route lengths for Runs 2 (100 ft), 3 (65 ft), and 4 (130 ft) that were deemed sufficient to represent the features of the terrain and which could enable the recording of an average speed through that terrain. Figures 9 and 10 show the terrain for Runs 3 and 4, respectively.

Table 3 Experimental design for mobility in various terrain

Run	Area	Terrain
1	1	UGV terrain course
2	3	Tall grass
3	3	Saplings with undergrowth
4	2	Mature woods with undergrowth

4. Demonstrated Configurations

In this section we describe the technologies included in the configuration used by each participating company. Table 4 lists the main component technologies that were available on the day of the assessment.

Table 4 Technology configurations for each company

Company designation	Capabilities
A	• A quadruped robot, which can be controlled through a Microsoft HoloLens • Optional control through a cell phone • Persistent Systems MPU5 tactical radio (with ~0.5-mile range) for communications between the platform and the operator • Obstacle avoidance when placed in the autonomous mode • Future capability: operation using voice commands
B	• Software and interface to remotely command and control both air and ground unmanned vehicles for security applications • Quadruped UGV system ○ An intelligence, surveillance, and reconnaissance enhancement package ▪ Electro-optical/IR gimballed payload with 720-pixel (p) electro-optical sensor with 20× optical zoom capability ▪ 640-p thermal imager • Compute module for interfacing with the robot ▪ An LTE radio for remote operations (command and control) ▪ Onboard cameras to provide real time obstacle avoidance ▪ A standard Xbox controller to control the robot • A self-docking charging station • Quadrotor unmanned aerial vehicle (not demonstrated)
C	• A quadruped robotic platform ○ Onboard lithium-ion battery ○ PTZ Optics 1080p color camera which incorporates pan, tilt and zoom features ○ A Sierra Olympic IR camera ○ Five fixed-color cameras (two pointing to the front, one pointing to the rear and one pointing out each side). ○ A Silvus Technologies Software Defined Tactical Radio for communicating between the robotic platform and the mission planning operating station. ○ Loudspeaker for engagement/response to potential intruders (only on one platform) • Local 5G network to provide local control communications. • Self-docking charging station

5. Evaluation Method and Analysis

Multiple onsite observers with various science, engineering, and military information backgrounds assessed the performance of the technologies. Prior to the data collection, the observers received a briefing by the performing technologists that described the design intent and functionality of the technologies. The evaluations consisted of notated feedback from the observers on the performance of the robot for each executed run. The observers were told that the context for use of the technology was that an expeditionary force of dismounted units was occupying a position near a named area of interest or a known asset. The unit required security and protection while they proceeded with their primary mission. The assumed purpose of the technology was to augment security by increasing situational awareness.

5.1 Analysis of Autonomy for Security: Urbanized Terrain

5.1.1 Company A

1) The initial attempts at detection were at a range of 140 m. This proved difficult for the given onboard perception suite as we tried to perform Runs 1 and 2. The robot was moved to the midway position of approximately 70 m. An attempt at Run 1 was successful but four attempts at Run 2 achieved only one detection. The robot was teleoperated forward, while an actor walked back and forth in the scene, until a detection was reliably achieved. It is from this range (~40 m) that we performed the remaining attempted runs.

2) Run 3: The system detected Pedestrian 1 as soon as the figure entered the detection bounding box with a 51% confidence value (note that only detections with a confidence value of greater than 50% were reported).

3) Run 4: Pedestrian 1 was detected after a significant time within view (~20 s); between locations M and D.

4) Run 5: No detection

5) Run 8: This run was modified to include two pedestrians to check if different clothing color or physical stature made a difference. Pedestrian 2, approximately 6 ft 2 inches in height and wearing a light gray shirt, was detected.

6) Run 9: The first unsuccessful attempt included Pedestrian 1, and for the second attempt, we introduced Pedestrian 3 (also unsuccessful). Pedestrian 2, the taller individual with the gray shirt, was used in a third attempt that yielded a detection.

7) Runs 12–14: For these replications we used Pedestrian 2 and introduced Pedestrian 4, of shorter stature wearing a white shirt. We found that only Pedestrian 2 was consistently detected. We suspect that the detection algorithm includes a height threshold that influenced the preference for this individual.

5.1.2 Company B

Some overall observations regarding system performance include that as soon as a target was within the platform's field of view (FOV), it was almost always detected and tracked immediately. However, tracking would sometimes be lost if a target moved into the shadows. The robot was positioned approximately 100 ft from the buildings.

1) Run 1: The target was detected as soon as it entered the FOV of the camera and was tracked until it went out of the FOV. The camera was zoomed in for this run. The run was repeated, and similar results were obtained.

2) Run 2: Both pedestrians walking from different directions were detected almost instantly when they entered the FOV. Tracking was intermittent for the course of the run. There was a small delay between when the targets were detected and when tracking started. Run 2 was repeated and similar results were obtained.

3) For Run 3, the target was detected and tracked until tracking was lost due to shadowing effects, which may have negatively affected the tracking algorithm. The camera was zoomed in (13.5 zoom) and Run 3 was repeated. The target was tracked for the entire run. The platform was operating in the user-enhanced detection mode.

4) During Run 4, the platform auto-tracked the two targets for almost the entire run. Both targets walked up the stairs, with one walking back down the stairs immediately (was tracked for the entire path) while the other target continued to walk to the front of the balcony. Tracking on the second target was lost when it was in the vicinity of the door.

5) During Run 5, the target was almost immediately detected once it emerged from the alcove of Building A. However, the platform did not continue to track the target when it disappeared behind Building B. An anomaly occurred insofar as the camera stopped tracking when the door on Building 2 entered the FOV. According to Company B, this could be because the platform went into a pixel tracking mode. When the target emerged from behind Building B, a new tracking number was assigned, indicating the start of new track. Camera was zoomed to 13.2.

6) For Run 6, the target was not initially detected behind the window (zoom was set to 13.2 initially). The camera was zoomed in (10.3 setting) and the target was detected. The run was repeated with two targets and both targets were detected (keeping the zoom at 10.3).

7) Run 7: The platform detected the vehicle first and then both pedestrians exiting the vehicle and tracked them until they went out of the FOV.

5.1.3 Company C

Some overall observations indicated that, for several of the runs, the IR camera detected the target before the color cameras did. In fact, in Run 1, the color camera did not detect the target at all. One potential cause might be due to the position of the sun with respect to the robot. If time allowed, it would have been beneficial to change the position of the robotic vehicles and the actors if for no other reason than to isolate the cause.

Originally, each of the runs was to be executed with one pedestrian. However, it was decided to test the ability of the demonstrated technologies to detect and track two pedestrians simultaneously. Again, due to time constraints, only four of the six runs were able to be executed. A secondary robotic vehicle was used for these vignettes to engage the detected target. The robots were teleoperated during this portion of the demonstration.

For Run 6 (targets in windows on both floors of the building), the camera had to zoom in to detect the bottom target (the top target was not detected). Again, this could be due to light reflection off the windows.

Times for detection were somewhat difficult to accurately measure since the color camera was panning during some of the runs. One observation was that a target was almost always detected once it passed within the FOV of the cameras.

5.2 Analysis of Autonomous Mobility

5.2.1 Company A

1) Run 1: On the first attempt at this baseline mobility run of 100-ft length, the robot exhibited a drift toward the right of the gravel path, achieved 75 ft in 25 s, and stepped into the ditch whereupon it collapsed. The robot was not able to self-recover. On the second attempt the robot achieved the full length in 30 s.

2) Run 2: This run was performed with the autonomous mode (obstacle avoidance) turned off and the robot driven by an operator via teleoperation through the mature woods. The vehicle traversed the 130-ft distance with an average speed of 3.1 ft/s.

3) Run 4: On the attempts in tall grass, the robot exhibited erratic behavior and was manually stopped as it rolled over at a traversed distance of 66 ft. A second attempt showed the same behavior, and the robot was stopped at a

traversed distance of 43 ft. The reported problem was a conflict between the obstacle avoidance behavior and the grass height and density. It was determined that further runs in such vegetation would be performed via teleoperation with the vision sensors off.

4) Run 8: On the terrain course the robot was teleoperated for two runs over the length of the 300-ft course (average speed was 3.8 ft/s and 4.0 ft/s). A third attempt was made with the autonomous mode turned on and over only one leg of the rectangular course (100-ft length). The robot successfully traversed the distance at an average speed of 2.9 ft/s.

5.2.2 Company B

Only Run 8 (the terrain course) was attempted for evaluating autonomous mobility and the course was traversed with the robot in a teleoperated mode. The run was started from the gravel/stone section of the course. The robot then proceeded to the synthetic grass section and then to the sandy area. The robot ran off its intended route several times, most likely due to latency in communications between the robot and the command-and-control software application due to being in a teleoperated mode. One of Company A's attendees provided the operator verbal feedback via cellphone to enable adjustments in the teleoperation of the robot.

The robot lost communications due to radio cables being damaged when it fell over. Since the cables were not secured, it may be beneficial to secure these cables in the future. A second robot was brought out, placed upside down and the self-right test was performed. The robot was able to successfully self-right. The robot was maneuvered to lay against one of the berms on the UGV terrain course and it was able to successfully self-right.

5.2.3 Company C

These vignettes appeared to be ideal for demonstrating the maneuvering capabilities of Company C's platform. That said, due to the interest of time, not all vignettes were executed. For Run 2 (wooded area near observation post [OP] 1), the course was traversed by the robotic vehicle first using a walking gait and then using a running gait. The vehicle was approximately 40% faster in the run mode when compared to the walk mode.

The robot seemed to perform well in the tall grass along the route (the platform stopped midway) and in the vignette with saplings (although it was teleoperated in both cases).

It was Company C's intention to traverse the UGV terrain course (100 ft × 50 ft) by taking four way points (one in each corner of the terrain course); however, without having satellite map imagery, sufficient accuracy of way point placement could not be achieved. Therefore, it was decided to have the robot traverse the course using the teleoperation mode and to continuously record way points (a less-than-ideal scenario in real-world applications). The video was turned off and the vehicle was operated in the proprioception mode (where the robot uses tactile feedback to assist in maneuvering the course). Using the pre-programmed way points, the robotic vehicle traversed the course. Although the robotic vehicle fell off the course path on several occasions, it was able to right itself in almost all instances. In the one case where the robot could not right itself, it employed a unique feature where the legs reversed themselves and the robot continued to operate "upside down" (which may be a misnomer since the sensors on the platform are basically symmetrically mounted so no measurable decrease in performance was noted).

5.3 Analysis of Autonomy for Security: Vegetated Trail Terrain

5.3.1 Company A

The initial attempts at detection were at a range of 140 m. This proved difficult for the given onboard perception suite as we tried to perform Runs 1 and 2. The robot was moved to the midway position of approximately 70 m. An attempt at Run 1 was successful but four attempts at Run 2 achieved only one detection. The robot was teleoperated forward, while an actor walked back and forth in the scene, until a detection was reliably achieved. It is from this range (~40 m) that we performed the remaining attempted runs.

1) Run 3: The system detected Pedestrian 1 as soon as the figure entered the detection bounding box with a 51% confidence value (note that only detections with a confidence value of greater than 50% were reported).

2) Run 4: Pedestrian 1 was detected after a significant time within view (~20 s); between locations M and D.

3) Run 5: No detection

4) Run 8: This run was modified to include two pedestrians to check if different clothing color or physical stature made a difference. Pedestrian 2, of approximately 6 ft 2 inches in height and wearing a light gray shirt, was detected.

5) Run 9: The first unsuccessful attempt included Pedestrian 1, and for the second attempt, we introduced Pedestrian 3 (also unsuccessful). Pedestrian 2, the taller individual with the gray shirt, was used in a third attempt, which yielded a detection.

6) Runs 12–14: For these replications we used Pedestrian 2 and introduced Pedestrian 4, of shorter stature wearing a white shirt. We found that only Pedestrian 2 was consistently detected. We suspect that the detection algorithm includes a height threshold that influenced the preference for this individual.

5.3.2 Company B

Many of the runs under this scenario were able to be executed. The OP was set up approximately 140 m from the position of the pedestrians, and the robot was placed just in front of the OP. Overall, as soon as the target entered the FOV, it was almost always detected. The results of the individual runs were as follows:

1) Run 1: The target was detected and tracked as soon as it entered the FOV.
2) Run 2: The target was detected and tracked as soon as it entered the FOV. However, the robot lost track when the target entered the grass.
3) Run 3: The target was tracked for almost the entire run.
4) Run 4: As soon as the target was in the FOV, it was detected.
5) Run 5: The robot tracked the target even when it was in the grassy area.
6) Run 6: The robot tracked the target while it was walking but lost track when the target crouched down (even though the target was not obscured by grass). The run was repeated with the camera zoomed in. The target was successfully tracked, even in the crouch position.
7) Run 7: The run was executed with the pedestrian holding a smaller object. The run was repeated with the target holding a larger object. In both instances the target was detected.
8) Run 8: The robot was moved up toward the area in which the pedestrians were stationed. The target was detected.
9) Run 9: The robot detected the vehicle and then the pedestrian behind the vehicle.
10) Run 10: The robot detected and tracked the target once it was passed the grass and tracked until the target passed behind the vehicle.
11) Run 12: The platform tracked both targets until point M and then tracked each individually from point M.
12) Run 17: The robot detected the vehicle after a time delay.

13) Run 20: The robot detected both the vehicle and the walking pedestrian (10.4 zoom). It also detected the driver and the passenger while in the vehicle.

14) Run 24: The robot detected the vehicle first, then the target entering vehicle, and finally the driver exiting the vehicle.

5.3.3 Company C

Although Company C's platforms were able to detect most targets at the range of 140 m (planned distance from the OP to the location from which the targets [actors] were located), the normal operating mode of the robot is to detect while in motion. To better demonstrate the capabilities of this technology, it was decided that the robot could proceed down the path from the OP to the targets while in the detection mode. This effectively reduced the range from 130 m to approximately 80 m or less. Both the IR and color cameras were used for detection. Video streaming and other information was streamed back to the OP using the Silvus radios.

6. Results

In this section we present a summary of the results of each company's technology by category, providing a tabular representation of the feedback followed by remarks for items that warrant discussion.

Feedback from the observers is organized into five categories: Perception/Detection, Mobility, Command and Control (C2), Autonomy, and User Experience. The feedback consists of qualitative statements about the advantages and disadvantages of the demonstrated performance. The advantages were deemed useful to the Army having potential to meet current and future needs. The disadvantages were considered things that are necessary to overcome before the technology will be useful to Soldiers in the field.

6.1 Perception/Detection

6.1.1 Company A

The system struggled to detect activity at reasonable ranges for situational awareness applications. The data reveals a limit to the number of activities and individuals that could repeatedly be detected. To make the robot more effective for surveillance, reconnaissance, and response applications, a more robust perception capability that can accommodate more classes, postures, activities, and partial concealment of personnel is required. Table 5 summarizes the advantages and disadvantages of the system for detection, and Figure 11 is a photograph of the robot.

Table 5 Results for detection performance: Company A

Advantages
• Able to detect faces • Detected movers above a specified threshold (50%)
Disadvantages
• Limited range for detection (30 m) • Consistently detected only one of three actors • Not trained to detect vehicles • Sensor package seemed equipped for only teleoperation and near-field situational awareness

Fig. 11 Company A technology in autonomy for security scenario on vegetated trail

6.1.2 Company B

The detection capability of the Company B technologies showed moderate effectiveness for people and objects, including those that move fast. Over the seven situations in the urbanized environment, the system detected single-person and double-person movement when those movers disappeared behind buildings and reappeared on the other side (appeared as a new detection ID). At times the detection was dropped and picked up again and occasionally delayed, but the technology could detect and track movers that climbed stairs, walked along second floor balconies, stood behind windows, and exited a vehicle. In Run 5 of the Autonomy for Security in Urbanized Terrain, the robot tracked the pedestrian when it entered the FOV and lost track when the pedestrian went behind the building. The robot did not track the pedestrian behind the building; the camera locked onto the door of Building B due to the system changing from object tracking to pixel tracking. Although this behavior was previously seen by the developers, this situation highlights the need to increase robustness in the detection and handling of detected information. The ability to lock on a detected entity for tracking is useful, and it is recommended that this capability be made reliable and seamless. Table 6 summarizes the advantages and disadvantages of the system for detection, and

Figure 12 shows the robot in the in the urban security scenario and an image of the display showing a detected person.

Table 6 Results for detection performance: Company B

Advantages
• Camera range and performance suited to scenarios (20× zoom)
• IR detector complements camera
• Fast detection
• Detection of people and objects
• Detection of fast movers
• Able to lock on detected entity (demo not seamless)
• Detection in grass up to half of figure
• Detection of person carrying object (not robust, required full view of figure)
• Detection through plastic and glass windows
Disadvantages
• Poor detection in shadows
• Difficulty detecting low silhouette
• Much user input required for some situations
• No history of detected entities
• Tracking hindered by pixel locking
• Area of detection box seemed restrictive

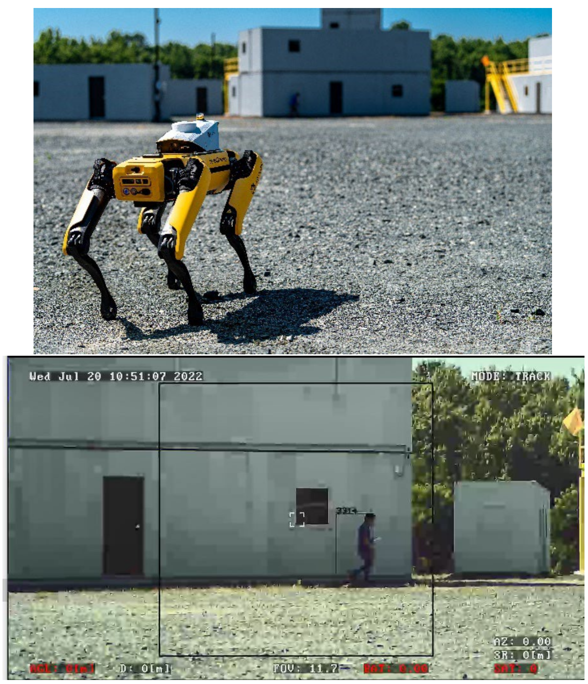

Fig. 12 Company B technology in autonomy for security scenario (top) and display showing detected person (bottom)

In the vegetated terrain, the system successfully detected moving personnel from 140-m standoff when the entities were clearly in view. The system struggled to detect people that were partially obscured and when they were in crouching positions and in shadows. Of concern is the amount of user input that was required to aid performance; for example, directing the system's attention to a location to detect activity.

6.1.3 Company C

The performance of the system for detecting activity in the two scenarios shows promise. Providing a range to detection is a useful feature and should be made available at any zoom setting. The conditions used in the assessment revealed that there are limited classes of entities that can be detected and classified. Classifications of humans were based on a 6-ft average height, which reflected limited detections for shorter individuals and less-than-upright posture. To increase utility, the ability to robustly detect personnel of various statures, in various postures, and while partially obscured is needed using all detection systems to the greatest possible extent. The ability to use thermal imaging for detection is desired, and it is recommended to find a solution that is on par with the color camera with respect to consistency of detection. Targets that were detected on the programmer's computer screen were not always displayed on the Mission Planning screen. If that was due to requiring human-in-the loop assistance, that ability should be integrated into the Mission Planning application using the required degree of autonomy. Detection on the move appeared to degrade as the cameras shook. Table 7 summarizes the advantages and disadvantages of the system for detection, and Figure 13 is two photographs of the robot in the urban and off-road environments.

Table 7 Results for detection performance: Company C

Advantages
• Can estimate ranges to detection
• Can classify movers
• Can detect through windows (when zoomed in)
Disadvantages
• Borderline detection of people in odd positions and in tall grass
• Thermal sensor detections were less reliable
• Limited detection software and training—mainly off-the-shelf

Fig. 13 Company C technology in autonomy for security scenario: (left) urban and (right) vegetated trail

6.2 Mobility

6.2.1 Company A

The mobility performance shows potential for using the demonstrated platform in off-road, challenging terrain. Robust self-righting after a rollover or crash is required to prevent the need for Soldiers to physically retrieve and handle the platform. The demonstrated capability for obstacle detection appears suitable to only open, relatively benign terrain. A minimum threshold for use in a teaming situation is robust obstacle avoidance in various terrains to include tall grass. This is a challenging requirement that requires new solutions to the negative obstacle problem. If these technologies are to accompany dismounted Soldiers that move through an area, the inherent platform mobility must permit traversal through those terrain types. Table 8 summarizes the advantages and disadvantages of the system for mobility, and Figure 14 is two photographs of the robot on the terrain course.

Table 8 Results for mobility performance: Company A

Advantages
• Robust teleoperated mobility
Disadvantages
• Obstacle avoidance caused overcorrection and instability
• Relatively slow mobility
• Unable to self-right after rollover

Fig. 14 Company A technology on terrain course

6.2.2 Company B

The lack of autonomous mobility limited the extend of possible mobility evaluations. The demonstrated mobility on the terrain course amounted to that provided by the Boston Dynamics Spot platform but with a disadvantage of communication latency. During the two attempted runs, the robot ran off the course many times. It was suspected that this was due to latency in communications from the laptop used to control the robot. To keep the robot on course, Company B personnel were required to be at the terrain course to provide corrections to the robot through the controller and those often resulted in overcorrections. The navigation trouble and accommodations held the platform to an average speed over the course of 1.44 ft/s. Table 9 summarizes the advantages and disadvantages of the system for mobility and Figure 15 is a photograph of the system on the terrain course.

Table 9 Results for mobility performance: Company B

Advantages
• Ability to follow pre-planned route • Power draw is low
Disadvantages
• Relatively slow mobility

Fig. 15 Company B technology on terrain course

6.2.3 Company C

The mobility performance of the platform in the various terrains is impressive. Average speeds across the assessment terrain were 1.85 ft/s on the terrain course; 3.12 ft/s in tall grass; 2.6 and 5.42 ft/s for walking and running gaits, respectively, in terrain with saplings; and 3.71 and 6.19 ft/s for walking and running gaits, respectively, in the mature woods. The demonstrated robustness of the platform provides confidence that it can go alongside and ahead of the Soldier for several environments. It is important that these technologies can operate on demand and without significant support from the user. The demonstrated ability of the robot to operate for long periods, classify terrain types, and apply different gaits are advantages for meeting those needs. The ability to follow way points (especially that have been entered using digitized maps) is a must-have feature and this needs to be simple to apply and reasonably accurate to ensure that the robot maneuvers as required. Table 10 summarizes the advantages and disadvantages of the system for mobility, and Figure 16 is a photograph of the system on the terrain course.

Table 10 Results for mobility performance: Company C

Advantages
• Very rugged • Moves quickly • Self-recovers well from a fall • Can follow GPS way points • Can use proprioception to identify terrain types • Can apply different gait modes per terrain classification • Useful battery endurance (3 h) • Waterproof (not demonstrated) • Basic collision avoidance
Disadvantages
• Heavy platform

Fig. 16 Company C technology on terrain course

6.3 Command and Control

6.3.1 Company A

The available features for informing the user about activities are a good starting point for useful control. The user interface display was limited to a map and a small alert section; however, the display of the confidence level for detection seemed useful and should be retained. The display capabilities could benefit from adding a video feed, alert playback, telemetry, and clear detection and classification information. The limited range over which the platform could be controlled, although possibly due to communications limitations, is a significant impediment to use, even as a teleoperated system. More specific feedback on that aspect appears in Section 6.5, User Experience. Table 11 summarizes the advantages and disadvantages of the system performance for C2, and Figure 17 shows the technology display for the vegetated trail scenario.

Table 11 **Results for C2 performance: Company A**

Advantages	
	• Alerts provided for detections
	• Interface display includes map
	• Interface available as phone app
Disadvantages	
	• No control of camera independently of platform orientation
	• Alerts delayed (apparently comms limited)
	• Limited operation distance

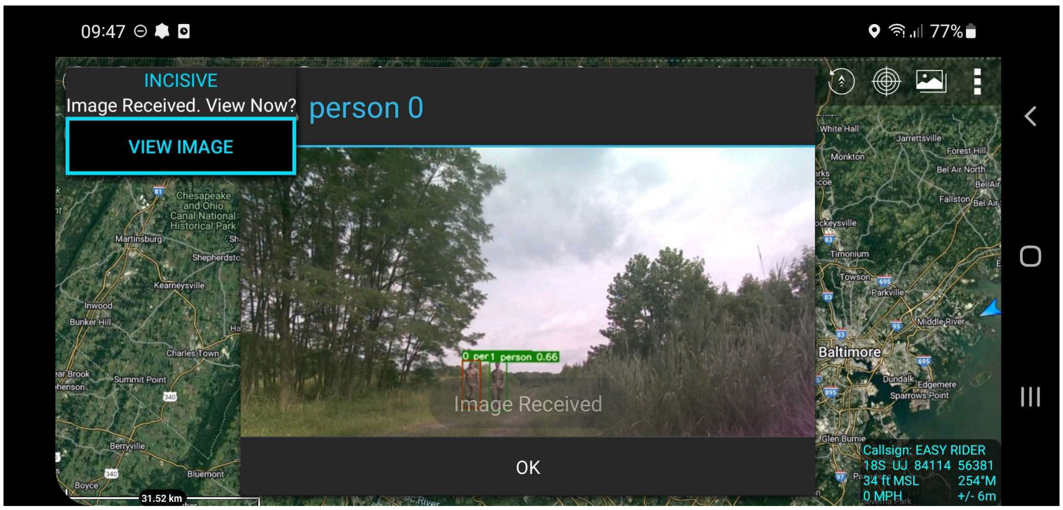

Fig. 17 Company A technology display

6.3.2 Company B

The features available for control and handling information provide a foundation for use of the system as an asset for reconnaissance, surveillance, and security applications. The fidelity of displayed video and information is sufficient for fast, effective situational awareness. Distributed control over distances that are only limited by cloud network availability enables a common operating picture at multiple levels and locations. Information sharing between assets should be built upon and expanded to include teaming capabilities for strategic behaviors (e.g., security concepts such as pursuer-evader behaviors). The observed trouble associated with communications losses emphasizes the need to provide a minimum level of autonomous mobility during times when data streams are intermittent or unavailable. Table 12 summarizes the advantages and disadvantages of the system performance for C2, and Figure 18 shows the technology display for the vegetated trail scenario.

Table 12 Results for C2 performance: Company B

Advantages
• Good video quality and stabilization
• Cross-platform information sharing
• Xbox controller easy to use
• Control and video across multiple platforms and control stations via cloud enables distributed operation
• Detection playback available (not immediate)
Disadvantages
• Telemetry features and setup confusing
• Black detection bounding box and telemetry font and color blended with background making comprehension difficult
• Unclear indication of classification
• Communications limitations (LTE) induced latency causing need for two operators on mobility course

Fig. 18 Company B robotics technology display with detection of partially obscured pedestrian

6.3.3 Company C

The C2 features provided useful visualization and levels of information. Alerts of detections were very clear and apparent and the ability to click on the alert, immediately or later, to obtain more information is useful. The open architecture is a plus for future development and adaptation to needs as they arise. Table 13 summarizes the advantages and disadvantages of the system performance for C2.

Table 13 Results for C2 performance: Company C

Advantages
• Provides root access to system • Detection appears on map • Notifications were useful (alerts and response capabilities) • Footage playback is useful • Controller display provides a sensed terrain visualization • Teleoperation controls are intuitive • Graphical User Interface (GUI) is intuitive and clean • Provides a non-lethal deterrent response option • Apparently useful for search and rescue • Ability to pursue detected entity is useful (demo was not seamless)
Disadvantages
• Alerts on display were delayed (comms problem) • Real-time video footage is not stabilized • Was not clear if MPU5 radio was used in demo; seemed mostly Wi-Fi network

6.4 Autonomy

6.4.1 Company A

The demonstrated capability for autonomy was minimal. This appears to be a product of the level of integration for other applications that did not account for conditions and situations of the assessment. A minimum capability for a robot used to alert Soldiers of activity is to enable the system to autonomously scan an area for activity and from a distance that enables concealment of the system. This requires detection of likely classes of activity, and it demands autonomy that puts the robot at a good vantage location with an initially broad view of the area. Another option to consider is mobile scanning to increase coverage and line-of-sight (LOS) opportunities. Table 14 summarizes the advantages and disadvantages of system performance for autonomy.

Table 14 Results for autonomy performance: Company A

Advantages
• Obstacle avoidance enabled mobility in limited situations
Disadvantages
• Few autonomy features

6.4.2 Company B

As demonstrated, the technology seems targeted as a teleoperated system or for limited applications that include structured environments and infrastructure with constant communications. Teleoperation might be sufficient for missions such as search and rescue but to meet broad Army requirements, especially for non-line-of-sight (NLOS) situations, some level of autonomy is critical. A minimum threshold for expanded utility is autonomous navigation and route selection. Table 15 summarizes the advantages and disadvantages of system performance for autonomy.

Table 15 Results for autonomy performance: Company B

Advantages
• Autonomous charging useful
Disadvantages
• Lack of autonomous route planning and navigation

6.4.3 Company C

As demonstrated, the technology proved useful as a teleoperated system or for limited applications in structured environments. A minimum threshold for expanded utility is autonomous navigation and route selection. The lack of a control loop for simultaneous obstacle detection and avoidance, stability control, and global navigation needs to be solved. In the Autonomy for Security scenarios, the reliance on the user to specify and zoom likely areas of activity needs to be alleviated. Table 16 summarizes the advantages and disadvantages of system performance for autonomy.

Table 16 Results for autonomy performance: Company C

Advantages
• For open areas can autonomously scan for activity (limited demo) • Detections can be shared between robots • C2 application provides weapon and response optimization (advertised, not demonstrated)
Disadvantages
• Lack of autonomous route selection • Relied on user to identify likely areas of activity

6.5 User Experience

6.5.1 Company A

The demonstrated performance appeared most suited to reconnaissance, surveillance, or perimeter security applications. If used for reconnaissance and surveillance, the technology must be controllable from a Command Post or Tactical Operations Center (TOC). Furthermore, to achieve concealment of the system from adversaries in terms of sight and sound, the detection and classification ranges must be significantly greater than demonstrated. If intended for use in perimeter security applications, the range for teleoperation must be significantly increased. Table 17 summarizes the advantages and disadvantages of system performance for user experience.

Table 17 Results for user experience: Company A

Advantages
• Showed some utility for close-in, manual control in structured environments
Disadvantages
• More development for autonomy and robustness required for potential Soldier use
• Small range of detection
• Small range of teleoperation

The Reserve Officers' Training Corps (ROTC) cadets that participated in the assessment reported the desire for automated response options for the robot. For example, when a detection occurs, the robot would be able to autonomously plan and navigate a path to the location of the detected activity to confirm the detection, classify the activity, and attain imagery.

6.5.2 Company B

As an LOS, teleoperated system, Company B's technologies can extend the reach of the user for limited purposes. In environments and conditions that provide structure, the current state of the technology could be used for security operations like perimeter integrity, closed-door and lock verification, and sharing video evidence of activity. We recognize that most of the development to date was focused on providing a mobile platform with improved sensing features and the framework for providing and acting upon information. To meet immediate Army needs such as NLOS and teaming requirements, future efforts to provide performance that exceeds commercial-off-the-shelf solutions is necessary. Table 18 summarizes the advantages and disadvantages of system performance for user experience.

Table 18 Results for user experience: Company B

Advantages
• Effective for perimeter security in structured environment (e.g., base operations)
• Ease of teleoperation training (10 min)
• Size and mobility seem suitable to squad use
Disadvantages
• Best limited to LOS operation
• Need reduced weight, better ruggedness, and increased payload while maintaining size
• Would like to see performance beyond that of You Only Look Once (YOLO) 5

6.5.3 Company C

Given the available capabilities and scenarios presented, the performance reveals that some structure in the environment and a priori data are required. The functionality showed limitations for team use in unstructured environments with unknown areas and when a unit requires each member to be responsible for security. If activity is known and suspected in certain places, the system may be suited to reconnaissance missions provided that the technology can be made transportable and robust. Table 19 summarizes the advantages and disadvantages of system performance for user experience, and Figure 19 shows a cadet operating the system.

Table 19 Results for user experience: Company C

Advantages
• System best suited to TOC and temporary perimeter security
• Feasible for reconnaissance/surveillance/observation missions
• Modular (can disassemble and replace parts in the field)
Disadvantages
• Demonstrated capabilities not likely ready for patrol missions

Fig. 19 ROTC cadet controls Company C technology on UGV terrain course

7. Summary and Conclusion

7.1 Summary

ARL and representatives from three companies gathered at the R2C2 at Aberdeen Proving Ground, Maryland, to demonstrate and evaluate ground robotics technologies with capabilities for protecting operating areas, personnel, and infrastructure in numerous types of environments and situations during its first ever IATA. The IATA provided an operationally relevant environment and problem set that enabled technology developers to demonstrate new technologies and apply existing technologies in innovative ways. It also provided a means for the government to assess and provide feedback on performance of technologies for known gaps and emerging needs.

The IATA scenarios consisted of mobility and situational awareness challenges that are relevant to security and protection of personnel and infrastructure. Two scenarios were used to present the challenges: Autonomy for Security and Autonomous Mobility. The Autonomy for Security scenario was conducted in two environments, the first consisting of a limited number of runs in the MOUT area and the second in a more-extensive set in the vegetated trail. The Autonomous Mobility assessment was conducted in the various terrains provided by the UGV terrain course and the other three terrain types consisting of tall grass, saplings with undergrowth, and mature woods with undergrowth.

The three participants were Asylon Robotics, Booz Allen Hamilton, and Ghost Robotics/ARES Security. Each of these brought quadruped UGVs with various sensory, computing, and situational awareness capabilities. Evaluations of each company's technologies were performed on different days and without the non-participating companies present.

Technologies were assessed for performance by multiple onsite observers with various science, engineering, and military information backgrounds from the Air Force Research Lab, DEVCOM Armaments Center, ARL, John Hopkins Applied Physics Laboratory, Marine Corps Warfighting Laboratory, and Test Resource Management Center. Prior to the data collection, the observers received a briefing by the performing technologists that described the design intent and functionality of the technologies. The evaluations consisted of notated feedback from the observers on the performance of the robot for each executed run. The observers were told that the context for use of the technology was an expeditionary force of dismounted units were occupying a position near a named area of interest or a known asset. The unit required security and protection while they proceeded with their primary mission. The assumed purpose of the technology was to augment security by increasing situational awareness.

7.1.1 Company A

On 18 July 2022, Company A and ARL gathered at R2C2 to demonstrate and evaluate Company A's ground robotics technologies at the first IATA event. The IATA provided an operationally relevant environment and problem set that enables technology developers to demonstrate new technologies and apply existing technologies in innovative ways.

Company A's technologies were evaluated for the ability to detect moving personnel and for mobility in various terrains. Limitations in the functionality of the configuration defined the scope of the data collection. The demonstrated performance appeared most suited to reconnaissance, surveillance, or perimeter security applications but with the need for further development and integration. The system struggled to detect activity at reasonable ranges for situational awareness applications and the number of activities and individuals that could repeatedly be detected were limited. It was apparent that the demonstrated mobility of the platform shows potential for use in off-road, challenging terrain. The available onboard autonomy was limited to obstacle avoidance, and which proved to be a disadvantage when attempting maneuver in tall grass, where the traversable terrain is concealed beneath the obstacles (i.e., grass), as the robot attempted to avoid the ground that it needed to walk on.

7.1.2 Company B

On 20 July 2022, Company B and ARL gathered at the R2C2 to demonstrate and evaluate Company B's ground robotics technologies at the first IATA event.

The detection scenarios of the IATA revealed that Company B's technologies are at the beginning stages of functions that are of interest to the Army. The features available for control and handling information provide a foundation for use of the system as an asset for reconnaissance, surveillance, and security applications. Increased robustness in the detection, classification, and reporting of activity is required. Further work is needed in the autonomy, particularly in autonomous mobility. A threshold for viability in unstructured environments is having obstacle detection and avoidance simultaneously with autonomous navigation. Furthermore, the less the system is dependent on the user for acquiring and using available information from the environment, the more applicable these legged robots will be for Soldier use.

7.1.3 Company C

On 21 July 2022, Company C and ARL gathered at the R2C2 to demonstrate and evaluate Company C's ground robotics technology at the first IATA event.

Over the various terrains and the two scenarios of Autonomy for Security and Autonomous Mobility, the Company C technologies performed well in several aspects. Strong mobility and robustness enabled the platform to maneuver at appreciable speed through each condition. The design characteristics for the user's role are apparent and bring this technology to the threshold of being viable for applications with structured environments and available a priori data for the areas of operation. Further work is needed in autonomy, particularly in autonomous mobility. A threshold for viability in unstructured environments is having obstacle detection and avoidance simultaneously with autonomous navigation.

7.2 Conclusion

The displayed technologies showed strengths in mobility across the various terrains and in most detection cases the actor was detected almost immediately upon entering the field of view. Some common areas that require improvement are autonomous mobility and response, clarity and usefulness of display information, and communications reliability. The systems usually struggled to detect people that were partially obscured and when they were in crouching positions and in some cases in shadows. Of concern is the amount of user input that was required to aid performance for mobility and detection of activity. A minimum threshold for expanded utility is autonomous navigation and route selection. The lack of a control loop for simultaneous obstacle detection and avoidance, stability control, and global navigation needs to be solved.

In this first IATA, companies participated in the event without funding from ARL. The companies brought technologies that they had readily available and applied them to the Army-relevant scenarios that were presented. The event was successful in that the participants experienced the environments and scenarios that these technologies will be subjected to for Army use, and it enabled ARL and the other observers to identify uses and cases for further development and collaboration for these off-the-shelf capabilities. Each company received detailed feedback in the form of a specific report given directly to them several weeks after the event. ARL learned many lessons from this first event on what to include in, and how to conduct, future assessments. Future IATA events will address different topics and focus areas determined by Army needs and the ARL research portfolio priorities.

List of Symbols, Abbreviations, and Acronyms

ARL	Army Research Laboratory
C2	Command and Control
DEVCOM	US Army Combat Capabilities Development Command
FOV	field of view
GPS	global positioning system
IATA	Industry Autonomy Technology Assessment
ID	identification
LOS	line of sight
MOUT	Military Operations on Urbanized Terrain
NLOS	non-line-of-sight
OP	observation post
p	pixel
R2C2	Robotics Research Collaboration Campus
ROTC	Reserve Officers' Training Corps
TOC	Tactical Operations Center
UGV	unmanned ground vehicle

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