# VISION 60 Q-Unmanned Ground Vehicle

## Technology Report

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Science and Technology

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# FOREWORD

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Urban Operational Experimentation (OpEx) 2022—hosted in July 2022 by the OpEx Program and National Urban Security Technology Laboratory (NUSTL)—provided first responders with the opportunity to experiment with new and emerging technologies in realistic, urban settings. This event combined demonstrations of leading-edge technologies with application-based field assessments staged throughout the New York City metropolitan area.

Urban OpEx 2022 was an important opportunity for DHS S&T to better understand the operational needs and requirements of urban first responders. Additionally, this event enabled first responder agencies to assess new technologies and provide feedback to participating technology vendors. Urban OpEx 2022 included participation from a broad range of federal, state, local, and private sector partners.

As part of the preparation for this event, DHS S&T facilitated discussions with first responder agencies to identify existing capability gaps. In coordination with NUSTL, the OpEx Program developed a Request for Information in light of these capability gaps soliciting interest from technology vendors who addressed the current needs, interests, and priorities of first responder organizations. DHS S&T selected technologies, in collaboration with first responder stakeholders, for participation in Urban OpEx 2022.

Urban OpEx events enrich the homeland security enterprise by gathering subject matter experts as first responder evaluators to train on and assess emerging technologies. First responder evaluators provided recommendations and feedback to technology vendors that can inform the refinement of existing technologies. Evaluator recommendations also provided valuable insight for the national first responder community to inform investments in new and emerging technologies.

For more information on Urban OpEx 2022 or to view additional Urban OpEx reports, visit www.dhs.gov/publications-library/science-and-technology.

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# EXECUTIVE SUMMARY

On July 19, 2022, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) conducted Urban Operational Experimentation (OpEx) 2022, during which participants evaluated the Vision 60 Q-Unmanned Ground Vehicle (hereafter referred to as "Vision"). Developed by Ghost Robotics, Vision is a quadrupedal deployable robotic platform suitable for use in a broad range of unstructured urban and natural environments for defense, homeland security, and enterprise security applications.

During Urban OpEx 2022, first responder evaluators piloted Vision in an operational scenario to provide feedback on its features and suitability for urban first responder organizations. Participating responders came from a variety of New York City agencies, including the Metropolitan Transportation Authority, New York City Emergency Management, New York City Fire Department, and New York City Police Department, as well as from the DHS S&T First Responder Resource Group,[1] including the Oswego Fire Department and San Diego Fire and Rescue. Ghost Robotics product engineers presented Vision's features and capabilities before evaluators operated Vision on unstructured terrain, a disabled bus, and a mock subway station. The Urban OpEx Planning Team incorporated first responder input to develop a list of critical tasks to accomplish while operating Vision. The Urban OpEx Planning Team also encouraged first responder evaluators to consider other ways outside of the identified critical tasks that they might use the technology during an actual event or incident.

The first responder evaluators found the Vision software intuitive and the controls easy to use. They were also impressed by Vision's ability to recover after a fall and return to a neutral standing position. Evaluators encountered a few challenges, however, including Vision's struggle to stay upright on slippery surfaces. Additionally, evaluators faced difficulty selecting the correct operational "mode" for traversing different types of terrain. As a result, evaluators had to toggle through the various modes or reset the robot, which took time and required vendor assistance.

The evaluators determined that Vision could enhance search and rescue operations. Still, its lack of maneuverability in tight spaces and difficulty traversing some obstacles might limit its usability in a dense urban environment. Suggestions include improving the robot's ability to traverse stairs and other obstacles without a manual change in the operational mode of travel. Due to time and scope limitations, Ghost Robotics did not equip Vision's thermal cameras, two-way radios, or chemical, biological, radiological, nuclear, and high-yield explosives sensors though these capabilities for the technology do exist. Many evaluators throughout experimentation said they would have liked to have seen these features.

[1] First Responders Resource Group is an all-volunteer working group comprised of 120 experienced emergency response and preparedness professionals (active and retired) that help S&T maintain focus on the top priority needs of responders in the field, helping to guide its research and development efforts.

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# 1.0 INTRODUCTION

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) supports first responders in their mission to protect the public by introducing them to new products and tools that enhance their operational effectiveness. The DHS S&T Operational Experimentation (OpEx) Program partnered with the National Urban Security Technology Laboratory (NUSTL) to plan, conduct, and assess Urban OpEx 2022.

To identify technologies with the highest utility for emergency response personnel, first responders from the Metropolitan Transportation Authority (MTA), New York City Emergency Management (NYCEM), New York City Fire Department (FDNY), and New York City Police Department (NYPD) identified capability gaps in their work and technology areas that could help to mitigate those gaps.

Using this input, the Urban OpEx Planning Team identified technology topic areas to address the first responders' capability gaps. DHS S&T then developed and disseminated a Request for Information (RFI) to solicit responses from vendors who offer products in those technology areas. Table 1 highlights Urban OpEx 2022 technology topic areas included in the event.

**Table 1: Urban OpEx Technology Areas**

| Topic Area | Description |
|---|---|
| **Fixed, On-body or Handheld Sensors** | Fixed, on-body or handheld technology solutions that can send and receive sensor data to support and enhance first responders' mission effectiveness. |
| **Unmanned Aircraft Systems (UAS)** | UAS technology solutions that provide the capability to survey and model urban environments. |
| **Situational Awareness Platforms** | Situational awareness technology solutions that provide necessary information to first responders to enhance disaster and emergency preparedness and response capabilities. |
| **Deployable Robotics** | Technology solutions that provide deployable robotics capabilities to support or enhance first responders' mission effectiveness. |
| **Deployable Communications Systems** | Technology solutions that provide deployable communications capabilities for use during an emergency or disaster, restoring failed communications systems or augmenting existing ones to increase capacity for emergency response functions. |
| **Video Content Analysis and Video Analytics** | Mobile and deployable technology solutions that aid law enforcement in threat detection, including but not limited to anomaly detection (e.g., bags left behind), behavior threat detection (e.g., crimes in progress, people in need of assistance), and facial recognition. |

DHS S&T used the technology topic areas to guide the selection process in consultation with subject matter experts (SMEs) from within S&T leading to the Urban OpEx Planning Team selecting seven technologies out of more than 50 RFI responses. The Urban OpEx Planning Team then worked with first responders, emergency response personnel, and technology vendors to develop operational scenarios and select venues for staging the experiments. In addition to scenario development, the Urban OpEx Planning Team created an Experimentation Plan (ExPlan) to guide the event. The ExPlan included information about logistics, safety, roles and responsibilities, experimentation design and scope, and evaluation guidance. Hosted by the OpEx Program and NUSTL, from July 19 to 22, 2022, New York City first responder agencies and members of the DHS S&T First Responder Resource Group (FRRG) experimented with the technologies and provided feedback and observations to inform technology development.

On July 19, 2022, first responder evaluators used the Vision 60 Q-Unmanned Ground Vehicle (UGV), a quadrupedal deployable robotic platform developed by Ghost Robotics as part of Urban OpEx 2022. SMEs from FDNY, MTA, NYCEM, NYPD, and FRRG participated as evaluators to assess Vision's utility for their respective agencies. Observers from the Port Authority of New York and New Jersey (PANYNJ) and various federal, state, and local partners also attended. Ghost Robotics participated in Urban OpEx 2022 under a Cooperative Research and Development Agreement (CRADA) with DHS S&T.

## 1.1 PURPOSE

The Urban OpEx Planning Team designed the Vision operational experiment to provide first responders and emergency response personnel with an opportunity to learn Vision's capabilities and limitations, gain hands-on knowledge in a representative environment, and provide feedback about Vision's applications for first responders and emergency response personnel. First responder evaluators gave feedback that could be used by Ghost Robotics to improve its Vision product. Likewise, the feedback gave S&T program managers a better understanding of first responders and emergency response needs to help guide future S&T investments.

## 1.2 OBJECTIVE

Urban OpEx 2022 will introduce new technologies and assess their ability to address first responder mission capability needs.

- Objective 1: Share end-user feedback on Vision with the national first responder community to inform their decision-making
- Objective 2: Share first responder feedback with Ghost Robotics to improve their products

## 1.3 RESPONDER CAPABILITY NEED

First responder SMEs who advised the Urban OpEx Planning Team on capability gaps indicated that deployable robotics could enhance urban search and rescue (USAR) capabilities by securing perimeters, roving terminals, and inspecting subway tracks. In this technology topic area, the first responders requested equipment that augments survivor identification and mitigation measures and protects personnel from hazards during a public safety emergency or disaster.

## 1.4 SCOPE

Due to time constraints and scenario limitations, evaluators and the Urban OpEx Planning Team could not experience all of Vision's features, capabilities, and configurations at Urban OpEx 2022. Technology training was limited to one hour of virtual training offered before Urban OpEx and one hour of in-person training at the event, which may have constrained how the evaluators interacted with the technology.

## 1.5 PRODUCT DESCRIPTION

Vision (Figure 1) is a medium-sized (96 pounds) UGV with an IP67 rating[2]. Vision allows end-users to operate in a broad range of law enforcement and emergency management use cases, including chemical, biological, radiological, nuclear, and high-yield explosive (CBRNE) detection and special weapons and tactics (SWAT) operations. The system can also act as a mobile video and multi-sensor platform and provide real-time feedback to central command centers.

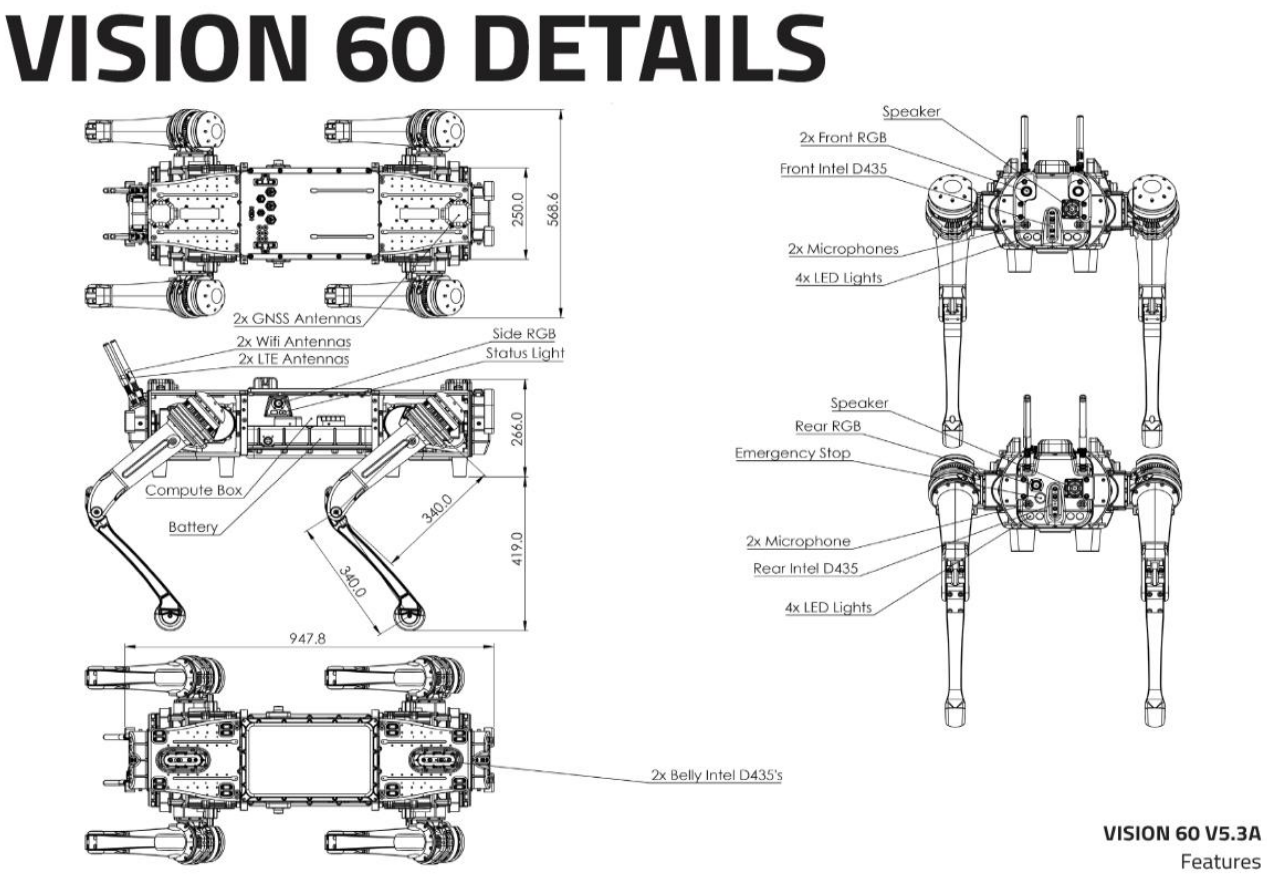


**Figure 1: Vision 60 Q-UGV Labeled Components**
*Image credit: Ghost Robotics*

[2] If a product is rated IP67, it is dust-tight and waterproof. The six indicates total protection against dust, and the seven indicates protection against short periods of time immersed in water between 15 centimeters and one meter. See "IP ratings" on the International Electrotechnical Commission website.

Its five built-in surround color cameras allow Vision operators to control it beyond their line of sight (LOS). Using the remote control (Figure 2), operators can select from a list of modes to aid in navigating various environments, including Blind Walk, Vision Walk, Vision Stairs, Hill Mode, Hill or Blind Curb, and Blind Curb. These settings alter Vision's gait and sensing capabilities to traverse grass, steps, curbs, stairs, steep inclines, sand, thick brush, and large rocks.

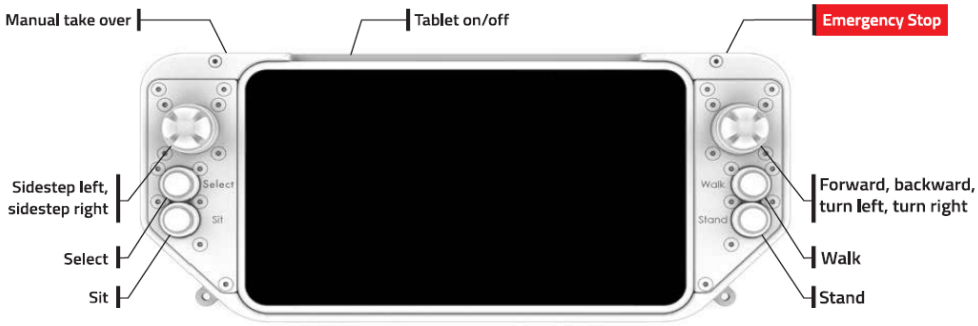


**Figure 2: Vision 60 Q-UGV Remote Control**
*Image credit: Ghost Robotics*

Vision uses onboard sensors to adjust for and traverse rugged terrain. If the robot falls over, it will automatically self-right and stand without user intervention. If the robot falls and ends up on its side or upside down, it can rotate its legs and remain fully operational in an inverted position (Figure 3) without user intervention.

Vision comes equipped with three sets of shoes (Figure 4) the standard set and then two additional designs meant to help the robot operate on different terrains. The "soft surface shoe" provides additional surface area for snowy, sandy, and soft surfaces. The "ice shoe" mimics a typical clamp-on style climbing boot to improve the robot's transversability on different surfaces. Given the scope and time limitations of the OpEx scenarios, first responders evaluated Vision with only its standard shoes.

**Figure 3: Vision 60 Q-UGV Operating while Inverted**
*Image credit: Ghost Robotics*

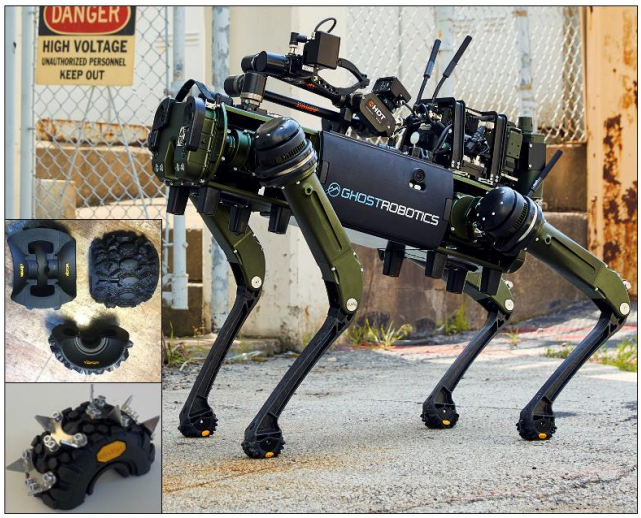


**Figure 4: Vision 60 Q-UGV Wearing "Standard Shoes" with Inset Images of "Soft Surface Shoes" (top) and "Ice Shoes" (bottom)**
*Image credit: Ghost Robotics*

## 2.0 EXPERIMENT DESIGN

The Urban OpEx Planning Team designed scenarios to allow first responders flexibility to experiment with features most relevant to their missions. Input from first responders, the technology vendor, the OpEx Program, and NUSTL's Experimentation Director helped develop scenarios that were not overly prescriptive but consistently engaged evaluators in testing the maneuverability and functionality of Vision (Figure 5 and Figure 6).

### Scenario:

An explosion is detected at Randall's Island. First responders believe survivors may be trapped in a rubble pile and bus, and that explosives may be in a nearby subway station.

Critical tasks to perform while using the robot included:

- Responding to pilot commands;
- Traversing uneven or slippery surfaces; and
- Relaying video feeds to a distant location without latency.

The first two critical tasks speak to Vision's maneuverability (i.e., ease of movement or steering while in motion). To test that factor, the Urban OpEx Planning Team instructed evaluators to maneuver Vision between several points over unstructured terrain (e.g., scrap metal, concrete piling, loose rocks, incline/decline). Evaluators switched between the different modes to test Vision's ability to navigate unstructured terrain, scrap metal, and enter a disabled bus. Evaluators operated Vision by keeping the robot within their LOS. When anything obstructed LOS, however, they used the camera views of the surrounding area - available on the remote control – (Figure 7) to operate it. Evaluators also reviewed Vision's functionality, or ability to fulfill the capabilities described by the vendor, before attempting the scenarios.

Figure 5: Vision 60 Q-UGV Atop a Car Door


Figure 6: Vision 60 Q-UGV in Mock Subway Car

Figure 7: Camera View on Remote Control

While exploring Vision's features and functions, first responder evaluators also got to see Vision's ability to relay video (Figure 8) to Incident Command (IC). Evaluators and observers who were not operating the remote controls viewed the video feed from Vision on a screen set up at a distant site to simulate IC. The video relayed clearly and with little latency, enabling simulated IC personnel to observe how the real-time video display and remote controls allowed operators to make decisions with little delay.

Figure 8: Vision Video Feed During OpEx

After evaluators completed the operational activities, the Urban OpEx Planning Team asked them to consider how this technology would affect their current standard operating procedures and whether Vision could augment their response capabilities.

## 2.1 SUMMARY OF THE OPERATIONAL EXPERIMENTATION

At Urban OpEx 2022, participants from FDNY, MTA, NYCEM, NYPD, and FRRG convened at the FDNY Fire Training Academy at Randall's Island in New York, New York to test and evaluate Vision (Figure 9). Before OpEx was underway, evaluators for Vision had the opportunity to participate in virtual technology training with vendors, allowing evaluators to familiarize themselves with the technology in advance of the live event.

Figure 9: Aerial View of All Hazards Simulator on Randall's Island
*Image credit: Google Earth*

Each evaluator was paired with at least one data collector who recorded their observations of the experiment along with real-time feedback from the evaluator. A TV monitor was available for anyone not engaged in hands-on experimentation to observe the Vision video and imaging feed; this doubled as an approximation of how Vision's video feed might be experienced inside an IC. Vision demonstrated rugged terrain mobility, damage assessment, and subway roving in Randall's Island's mock subway. Table 2 summarizes the equipment used for the experiment.

Table 2: Equipment Used During Experimentation

| Equipment | Description |
|---|---|
| Vision 60 Q-UGV | Quadrupedal Unmanned Ground Vehicle |
| Vision Controller | Controls/operates UGV |
| Roku TV & Stand | Visualization of UVG video/imaging feeds |
| Payloads | Video camera and wireless router |

### 2.1.1 CONDUCTING EXPERIMENTATION ACTIVITIES

Activities began in a classroom with a presentation by personnel from the OpEx Program, NUSTL, and FDNY, which provided an overview of Urban OpEx and its purpose. The Experimentation Director provided opening remarks and a safety briefing. Ghost Robotics technology vendors then provided an overview of Vision and its capabilities and trained evaluators on its operation. After approximately 30 minutes of hands-on training, (Figure 10), the experimentation activities began.

Figure 10: Vision 60 Q-UGV During Training

The operational experimentation was divided into scenarios focused on using Vision to traverse unstructured terrain, aid in damage assessment, locate a survivor, and rove through a mock subway station along subway tracks. These scenarios tested Vision's ability to move through various environments that urban first responders may encounter in emergency response.

First, evaluators maneuvered Vision along a predetermined course in the All-Hazards Simulator, a large area filled with rubble, abandoned vehicles and other obstacles, to assess its ability to navigate unstructured terrain, including loose rocks and scrap metal. The evaluators selected from the robot's six modes for moving through the various environments: Blind Walk, Vision Walk, Vision Stairs, Hill Mode, Hill or Blind Curb, and Blind Curb.

For the second scenario, evaluators operated Vision to enter a disabled city bus from the rear entrance, approach the front to inspect a mock survivor (a mannequin), and go back to the rear entrance to exit the bus (Figure 11). Vision's cameras provided a high-resolution live video for evaluators and observers to quickly locate the mannequin mock survivor inside the bus. Evaluators experimented with Vision's mobility at the disabled bus's entryway before receiving guidance from Ghost Robotics representatives to select "stair" mode. Once in stair mode, they could successfully enter the bus to carry out the simulated search and rescue mission.


Figure 11: Vision 60-UGV Experimentation on Disabled Bus

Finally, evaluators tested Vision's ability to move through a mock subway station (Figure 12). Evaluators navigated the mock subway station, cleared gaps, and moved through the subway cars and tracks. Ghost Robotics provided guidance to evaluators to help them navigate the subway environment.

The hands-on experimentation continued until each evaluator had an opportunity to use Vision in each location. Ghost Robotics representatives were available to answer questions and provide technical assistance as requested during the hands-on experimentation. Otherwise, the technology representatives remained hands-off, allowing for uninterrupted assessment of the technology.

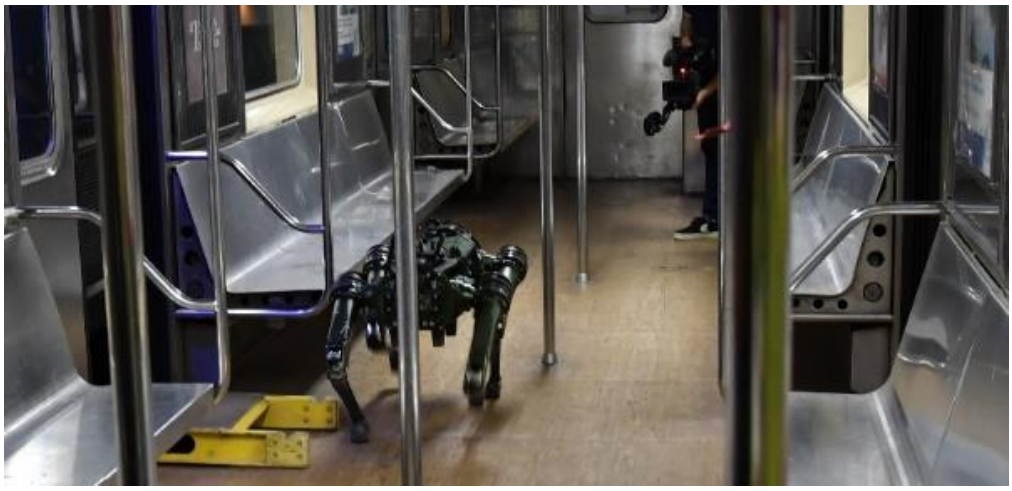

Figure 12: Vision 60 Q-UGV in Mock Subway at Randall's Island

## 2.2 DATA COLLECTION

Throughout the experiment, the Urban OpEx Planning Team also encouraged evaluators to voice their opinions to assigned data collectors. The Urban OpEx Planning Team and NUSTL obtained feedback from the evaluators in several ways:

- During the test activities, at least one data collector worked with each evaluator to record comments, concerns, and difficulties using Vision
- After participating in the scenarios, evaluators completed a questionnaire that captured their opinions on the suitability of Vision for first responders and emergency response agencies
- Finally, the Experimentation Director led a technology debriefing during which evaluators provided additional comments and feedback that data collectors recorded. The discussion included the following questions:
  - In what applications do you anticipate using this technology?
  - What did you like about this technology?
  - What did you dislike about this technology?
  - What changes would you recommend? Why?
  - Is this technology something that you would actively use if it was available to you?
  - How do you think this technology would affect your ability to complete your duties?

# 3.0 RESULTS

The results for the Urban OpEx 2022 evaluation of Vision contain three types of feedback: questionnaire feedback, data collector notes, and technology debrief notes. These results will help first responder agencies understand whether Vision may be suitable for their operations and provide information to Ghost Robotics on strengths and opportunities for improvement for their technology. Each of the evaluators come from different domains, regions, specializations, and levels of experience. These diverse experiences give context to user feedback that may at times appear contradictory. However, most evaluators made similar evaluations to one another unless otherwise noted.

## 3.1 QUESTIONNAIRE FEEDBACK

Each evaluator completed a questionnaire on technology suitability, ease of use, and most useful features. The first part of the questionnaire asked the evaluators to respond to a series of statements about Vision's suitability for incident management missions and ease of use. Table 3 provides these questions and a breakdown of user responses. The number in each table cell represents the total number of evaluators who selected Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree, or Unable to Determine when completing their evaluation. All evaluators agreed that Vision could be used to help fulfill their agency's mission. Six out of seven evaluators indicated that Vision was an improvement over the technology they currently use. Evaluators unanimously agreed that the user interface was intuitive, easy to engage with, and understandable. They also indicated that Vision would improve their ability during a multiagency response to communicate, share information, and coordinate with other agencies or groups by providing real-time video to incident commanders.

Figure 13: Evaluators Testing Vision 60 U-UGV at Randall's Island All Hazards Simulator

Table 3: Evaluators' Responses to Questions on Suitability and Ease of Use

| Equipment | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree | Unable to Determine |
|---|---|---|---|---|---|---|
| This technology can help urban first responders' missions. | 0 | 0 | 0 | 1 | 6 | 0 |
| This technology is an improvement on the technology urban first responders currently use. | 0 | 0 | 1 | 4 | 2 | 0 |
| This technology performed all capabilities outlined by vendor. | 0 | 0 | 0 | 5 | 2 | 0 |
| Responders are able to easily use this technology in conjunction with their required personal protective gear, if applicable to the scenario. | 0 | 0 | 0 | 3 | 3 | 1 |
| The computer/mobile device user interface was intuitive and easy to both understand and engage with. | 0 | 0 | 0 | 1 | 6 | 0 |
| The technology was easy to use with little to no interference from vendor during testing. | 0 | 0 | 0 | 4 | 3 | 0 |
| This technology increases urban first responder's ability to communicate and disseminate information during an event or incident. | 0 | 0 | 0 | 6 | 1 | 0 |
| This technology can improve first responder's ability to communicate and coordinate with other agencies and groups. | 0 | 3 | 0 | 2 | 1 | 1 |
| This technology can improve my ability to review and report information back to my leadership. | 0 | 0 | 1 | 1 | 5 | 0 |
| This technology should be recommended to other urban first responders. | 0 | 0 | 0 | 3 | 3 | 1 |

Part two of the questionnaire asked evaluators open-ended questions to describe what features they found most and least useful. Some evaluators expanded upon their answers by describing potential solutions to troubleshoot the issues they faced when operating Vision. Most evaluators believed that Vision could be an asset to their organization. Still, some believe the range of use cases is narrow and said they would need to see additional use cases (e.g., chemical detection) to decide on overall utility.

During the operational activities, data collectors recorded evaluators' comments about positive attributes and challenges they experienced while operating Vision. Data collectors also documented technical issues and noted evaluators' concerns (all minor) about the user interface and capability limitations. After the scenarios concluded, the debriefing allowed the data collectors to solicit further feedback from the evaluators. Table 4 summarizes evaluators' responses from the activities and debriefing as recorded by data collectors. The feedback falls under three categories: remote control, optics, and UGV handling.

**Table 4: Evaluators' Responses to Questions on Vision's Features**

| Application | Most Useful Features | Least Useful Features/Problems | Recommendations |
|---|---|---|---|
| Remote Control | ▪ Switching between movement modes is easy (e.g., curb mode, hill mode, etc.)<br>▪ Controls are well-labeled, smooth/fluid, intuitive, and easy to operate<br>▪ Video displays on the remote control allow easy control without LOS<br>▪ Ergonomic remote control is comfortable for long periods<br>▪ Video display screen on remote control makes it easy to control without LOS | ▪ Remote control lost connection with the UGV during one iteration, causing the UGV to collide with an obstacle and requiring a manual reboot from the technology developer of the entire system (controller and UGV)<br>▪ When operating the system outdoors in direct sunlight, glare on the controller screen impeded evaluators' ability to see it<br>▪ Evaluators had difficulty switching from Wi-Fi to LTE on the remote control because of its size | ▪ Collision indicator on the remote-control screen would be helpful for when operating without LOS |
| Optics | ▪ Camera feed is clear and without latency<br>▪ Cameras are an overall asset, especially the rear-view<br>▪ Camera allowed evaluators to correctly identify the mannequin "survivor" | ▪ According to the vendor, thermal optics are limited to relative temperature and cannot display absolute temperature<br>▪ Camera did not reorient itself when the robot fell over and recovered, resulting in an upside-down view | ▪ 360° cameras would be useful when moving in austere environments<br>▪ Three-dimensional (3D)-mapping and light detection and ranging (LiDAR) could be helpful for maneuvering and obstacle avoidance |

| Application | Most Useful Features | Least Useful Features/Problems | Recommendations |
|---|---|---|---|
| UGV handling | ▪ Well-equipped for stairs. In both Vision and stairs mode, Vision easily ascended the stairs and moved about the bus<br>▪ Traverses small rocks easily<br>▪ Includes run/walk features<br>▪ Operates well in "run" mode<br>▪ Can walk while inverted<br>▪ Able to traverse between subway car gaps<br>▪ Flexible joints allow for easy maneuverability in turning and during orientation<br>▪ Sensors are highly sensitive and improved the user experience<br>▪ Impressive object detection, avoidance, and self-righting feature<br>▪ Sit and stand modes are helpful<br>▪ Quick start-up (around one minute)<br>▪ Easily accommodates other payloads to assist with mission-specific tasks<br>▪ Overall operation is very intuitive, and it responded well to commands | ▪ Steep terrain, subway tracks, and concrete slab troublesome; lost footing on slick metal and struggled on large gravel<br>▪ Autonomous self-correction results were inconsistent. In one case, the UGV had to be manually corrected by a vendor after self-correction failed<br>▪ Size makes tight turns difficult<br>▪ Stability on rough terrain was a primary concern<br>▪ Repeatedly collided with obstacles such as vertical pipes and handrails in the subway due to its size in a limited space<br>▪ Input lag between the controller and UGV, resulting in slightly delayed movements, especially when out of LOS<br>▪ Vision's movements were "hesitant" in the unstable subway environment<br>▪ One evaluator had issues with input lag<br>▪ One evaluator described Vision as "not robust"<br>▪ Decontamination process or instructions are absent | ▪ "Feet" could have more grip and be more prominent for increased stability *<br>▪ Dense urban environments are an area for improvement because of the difficulty maneuvering in tight spaces with many obstacles and because of the diversity of surfaces encountered<br>▪ Better integration of external accessories or customizations into the platform could help support a variety of mission capabilities (e.g., sensor integration, two-way communications, thermal imaging) |
| * Ghost Robotics has additional shoe attachments that increase stability and grip on different types of surfaces, however, they were not included in the experimentation at Urban OpEx 2022 due to scenario and time constraints set by the Urban OpEx Planning Team. | | | |

# 4.0 CONCLUSION

Evaluators' feedback on Vision was generally positive. Throughout the written questionnaire and during the debriefing, evaluators remarked that the technology's intuitive design and robust functionality are positive attributes that would make them more likely to use it. Evaluators found that Vision's ability to provide live footage back to IC of austere and otherwise inaccessible environments would increase situational awareness and enable responders to make more informed decisions.

A majority of evaluators also noted several shortcomings they encountered while using Vision. For example, the robot struggled to maneuver through rough terrain, indicating that Vision may not be suitable for special operations use cases. Evaluators also noted that the robot's large size and bulky frame are limiting factors when operating in confined environments such as the tracks beneath subway cars. Vision could not maneuver in and out of tight areas where potentially hazardous objects or rescue subjects are located in real-world emergencies. Throughout the scenarios, evaluators experienced difficulty selecting the correct operational mode for traversing different types of terrain, which slowed down their ability to move from one terrain type to the next (e.g., flat ground to stairs or a bus entrance).

Evaluators offered multiple solutions to address these problems, including:

- Increasing the size, material, or shape of Vision's feet to create better stability and improve traction on smooth or slippery surfaces[3]
- Reducing the size of and rounding Vision's shoulders to maneuver better in tight environments
- Improving Vision's ability to traverse stairs and other obstacles without a manual change in the operational mode

Evaluators also offered some recommendations to extend Vision's capabilities by integrating with other technologies or tools used by first responders, specifically:

- 360° cameras for complete LOS
- Two-way communication tools
- Sensor integration using third-party CBRNE sensors, thermal sensors, and payload attachments

The evaluators' feedback will be shared with Ghost Robotics, enabling the technology vendor to continue improving their product and potentially expanding the number of use cases in which Vision could support first responders' work. Urban OpEx 2022 experiments were conducted in a half-day timeframe. They were driven by a tailored set of scenarios that limited the evaluator's exposure to a typical training program, broader technology configurations outside the planned scenarios, and additional features/configurations of the technology not applicable to the scenarios. Given these constraints, it is possible that some first responder evaluator feedback or suggestions for improvement could be addressed at the user level through completing the entire technology provider-recommended training program.

[3] Ghost Robotics has additional shoe attachments that increase stability and grip on different types of surfaces, however, they were not included in the experimentation at Urban OpEx 2022 due to scenario and time constraints set by the Urban OpEx Planning Team.

# 5.0 ACRONYM LIST

| Acronym | Definition |
|---|---|
| 3D | Three-dimensional |
| CBRNE | Chemical, Biological, Radiological, Nuclear, and Explosives |
| CRADA | Cooperative Research and Development Agreement |
| DHS | Department of Homeland Security |
| FDNY | New York City Fire Department |
| FRRG | First Responder Resource Group |
| GNSS | Global Navigational Satellite Systems |
| IC | Incident Command |
| LED | Light Emitting Diode |
| LiDAR | Light Detection and Ranging |
| LOS | Line of Sight |
| LTE | Long Term Evolution (e.g., 4G or Fourth Generation) |
| MTA | Metropolitan Transportation Authority |
| NYCEM | New York City Emergency Management |
| NYPD | New York City Police Department |
| NUSTL | National Urban Security Technology Laboratory |
| OpEx | Operational Experimentation |
| PANYNJ | Port Authority of New York and New Jersey |
| RFI | Request for Information |
| RGB | Red, Green, Blue |
| SME | Subject Matter Expert |
| S&T | Science and Technology Directorate |
| SWAT | Special Weapons and Tactics |
| UAS | Unmanned Aircraft System |
| UGV | Unmanned Ground Vehicle |
| USAR | Urban Search and Rescue |