Defense Systems Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Aritificial Intelligence (AI)-Enabled Ground Vehicles

Report Number:

DSIAC-BCO-2024-587

Completed September 2024

DSIAC is a U.S. Department of Defense Information Analysis Center

MAIN OFFICE
4695 Millennium Drive
Belcamp, MD 21017-1505
Office: 443-360-4600

REPORT PREPARED BY:
Taylor H. Knight
Office: DSIAC

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 18-09-2024	**2. REPORT TYPE** Technical Research Report	**3. DATES COVERED** *(From – To)*
4. TITLE AND SUBTITLE Artificial Intelligence (AI)-Enabled Ground Vehicles		**5a. CONTRACT NUMBER** FA8075-21-D-0001 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Taylor H. Knight		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Defense Systems Information Analysis Center (DSIAC) SURVICE Engineering Company 4695 Millennium Drive Belcamp, MD 21017-1505		**8. PERFORMING ORGANIZATION REPORT NUMBER** DSIAC-BCO-2024-587
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Defense Technical Information Center (DTIC) 8725 John J. Kingman Road Fort Belvoir, VA 22060-6218		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES

Autonomy, Human/Autonomous System Interaction and Collaboration, Autonomous Systems, Weapon Systems

14. ABSTRACT

The Defense Systems Information Analysis Center was asked to identify programs performing research on artificial intelligence (AI)-enabled ground vehicles in the U.S. Department of Defense (DoD). Using AI-enabled ground vehicles, often referred to as unmanned ground vehicles (UGVs), allows increased adaptability on the battlefield by operating without a physical driver. Uses include scanning and identifying enemy threats, relaying images of targets, and informing target engagement. UGVs aim to be highly responsive and adaptive in a variety of scenarios such as combat, communication, reconnaissance, and target engagement options. They can support high-risk missions while minimizing the risk to troops and soldiers. A list of notable DoD organizations and programs performing research in this area is included in this report, followed by a summary of their relevant work.

15. SUBJECT TERMS

artificial intelligence, AI, unmanned ground vehicles, UGV

16. SECURITY CLASSIFICATION OF: U			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Ted Welsh, DSIAC Director
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	16	**19b. TELEPHONE NUMBER** *(include area code)* 443-360-4600

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

About

DTIC and DSIAC

The Defense Technical Information Center (DTIC) preserves, curates, and shares knowledge from the U.S. Department of Defense's (DoD's) annual multibillion-dollar investment in science and technology, multiplying the value and accelerating capability to the Warfighter. DTIC amplifies this investment by collecting information and enhancing the digital search, analysis, and collaboration tools that make information widely available to decision-makers, researchers, engineers, and scientists across the Department.

DTIC sponsors the DoD Information Analysis Centers (DoDIAC), which provide critical, flexible, and cutting-edge research and analysis to produce relevant and reusable scientific and technical information for acquisition program managers, DoD laboratories, Program Executive Offices, and Combatant Commands. The IACs are staffed by, or have access to, hundreds of scientists, engineers, and information specialists who provide research and analysis to customers with diverse, complex, and challenging requirements.

The Defense Systems Information Analysis Center (DSIAC) is a DoDIAC sponsored by DTIC to provide expertise in 10 technical focus areas: weapons systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability (RMQSI); advanced materials; military sensing; autonomous systems; energetics; directed energy; nonlethal weapons; and command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). DSIAC is operated by SURVICE Engineering Company under contract FA8075-21-D-0001.

TI Research

A chief service of the U.S. Department of Defense's Information Analysis Centers is free technical inquiry (TI) research limited to four research hours per inquiry. This TI response report summarizes the research findings of one such inquiry. Given the limited duration of the research effort, this report is not intended to be a deep, comprehensive analysis but rather a curated compilation of relevant information to give the reader/inquirer a "head start" or direction for continued research.

Abstract

The Defense Systems Information Analysis Center was asked to identify programs performing research on artificial intelligence (AI)-enabled ground vehicles in the U.S. Department of Defense (DoD). Using AI-enabled ground vehicles, often referred to as unmanned ground vehicles (UGVs), allows increased adaptability on the battlefield by operating without a physical driver. Uses include scanning and identifying enemy threats, relaying images of targets, and informing target engagement. UGVs aim to be highly responsive and adaptive in a variety of scenarios such as combat, communication, reconnaissance, and target engagement options. They can support high-risk missions while minimizing the risk to troops and soldiers. A list of notable DoD organizations and programs performing research in this area is included in this report, followed by a summary of their relevant work.

Defense Systems Information Analysis Center

Contents

1.0 TI Request

1.1 Inquiry

What are current U.S. Department of Defense (DoD) programs or projects related to artificial intelligence (AI)-enabled ground vehicles?

1.2 Description

The inquirer is looking for current research, programs, and/or projects on AI-enabled ground vehicles, particularly from the DoD. Summaries of the programs are provided.

2.0 TI Response

A common question asked within the DoD is, "How can we protect our soldiers more?" Using AI to minimize human risk has been an ever-present goal among researchers in the U.S. government and DoD, including for use in ground vehicles. Identifying methods for creating autonomy in ground vehicles has led to the exploration of AI-enabled ground vehicles, or unmanned ground vehicles (UGVs). Vehicles that can operate without a physical driver allow increased adaptability on the battlefield and a variety of use cases, such as scanning and identifying enemy threats, "rapidly relay[ing] images of detected targets to a human-led command center," informing engagement of targets, and enhancing "speed and accuracy of tactical movements while minimizing the need to mobilize scout troops." AI-enabled ground vehicles aim to be "highly responsive and adaptive" in a variety of scenarios, such as fighting, communication, reconnaissance, and target engagement options [1].

The Defense Systems Information Analysis Center (DSIAC) was asked to identify DoD programs or projects related to AI-enabled ground vehicles and provide summaries of their research and/or projects. DSIAC staff searched open-source documents and the Defense Technical Information Center's Research and Engineering Gateway to identify related information. Summaries of projects and programs are included, listed alphabetically by organization.

2.1 Defense Advanced Research Projects Agency (DARPA)

DARPA is involved with a few projects offering AI-enabled systems for ground vehicle use, such as the Learning Introspective Control program (LINC) and the Robotic Autonomy in Complex Environments With Resiliency program (RACER). Both aim to give ground vehicles more autonomy in the field.

2.1.1 LINC

DARPA awarded $9.3M to New Jersey-based Peraton Labs for its LINC project, which aims to develop AI technologies that allow systems to "examine their own decision-making processes in enabling" UGVs to respond to situations "not predicted at the time these systems were designed." LINC will "characterize unforeseen circumstances" and then "update the control law to maintain stability and control" [2]. This will help UGV operators maintain control of military platforms that have been modified or damaged in conflict or the field. The LINC-equipped platform can compare the current behavior of a platform (measured by onboard sensors) to a learned model of the same system and update a control law as needed.

2.1.2 RACER

DARPA is developing and testing algorithm technologies that allow UGVs to "maneuver on unstructured off-road terrain at speeds that are only limited by considerations of sensor performance, mechanical constraints, and safety" [3]. The goal is to allow the software to attain off-road speeds and maneuverability like those achieved by a human driver.

Phase 1 testing was completed in March 2022, and Phase 2 testing finished in the fall of 2023. Phase 1 testing demonstrated self-driving vehicles based on the Polaris RZR S4 1000 platform that were equipped with "360-degree range and image sensing such as multiple LIDARs (light detection and ranging), stereo camera pairs, color and infrared imaging cameras, RADAR [radio detection and ranging], event sensors, and inertial measurement sensing" [4].

Phase 2 of the RACER program tested autonomous movement on larger UGVs, designated as RACER heavy platform (RHP) vehicles. They are 12-ton, 20-ft long, skid-steer tracked vehicles and complement the RACER fleet vehicles (RFVs) already in use. The RHP vehicles uses the Textron M5 base platform, which is used in U.S. Army campaigns and is "supported for RACER autonomy integration hardware stacks and software by Carnegie Robotics" [5].

RACER's "goal of platform agnostic autonomy in [unpredictable] complex, mission-relevant off-road environments" is being advanced in Phase 2 with the use of "combat-scale RHPs." Teams from the University of Washington and the National Aeronautics and Space Administration's Jet Propulsion Laboratory tested the RHPs at a military training area in Texas. Unoccupied RFVs "demonstrated autonomous movement within a [diverse and varied] 15-square-mile terrain area." The teams completed more than 30 autonomous runs, including night runs, ranging from 3 to 10 miles at a time, "achieving over 150 autonomous, unoccupied miles at speeds up to 30 mph" [5].

The results of the Phase 2 tests reveal that the RHPs are achieving "tougher autonomous maneuver goals while showing autonomy resiliency and adaptability to new environments on any robot at any scale," according to Dr. Stuart Young, RACER's program manager. RACER is planning two field tests in 2024 [5].

2.2 Defense Innovation Unit (DIU)

The DIU partnered with the Army to "prototype autonomous software and processes to adapt uncrewed vehicle technology" to varied military challenges and environments. The Ground Vehicle Autonomous Pathways (GVAP) project aims to prototype software to navigate UGVs by "fusing data from multiple sensors and allow for teleoperations." GVAP will offer a "pipeline to continue rapid modeling, testing, evaluation, development, and deployment of autonomous features as they become commercially available" [6].

Over 100 responses were received by DIU and then narrowed down and selected by a panel of DoD subject matter experts. The following companies were selected to work on the prototype [6]:

- Autonomous Navigation: Forterra, Kodiak Robotics, Neya Systems, and Overland AI
- Machine Learning (ML) and Autonomy Pipeline: Applied Intuition, Inc., and Scale AI
- Software System Integrators: Anduril Industries and Palantir Technologies

Kodiak Robotics was awarded $50M to [7]:

> …leverage its commercial self-driving software to develop, test, and deploy autonomous capabilities for driverless vehicles that further strengthen national security. Kodiak will develop autonomous vehicle technology for the Army to navigate complex terrain, diverse operational conditions, and GPS-challenged environments, while also providing the Army [with] the ability to remotely operate vehicles when necessary.

Chosen vendors will support the Army's Robotic Combat Vehicle (RCV) program in developing "a robust, capable, and compliant software system that can operate in a variety of autonomous modes and rapidly integrate a variety of payloads." The goal is to use AI-enabled UGVs "to support high-risk missions and reduce risk for combat troops in military operations," as well as allow for reconnaissance in "fast, complex, and lethal" ground environments [6].

2.3 U.S. Army

Most of the research on AI-enabled ground vehicles was found to fall under the Army. There are multiple programs and projects working toward creating autonomous UGVs.

2.3.1 U.S. Army Artificial Intelligence Integration Center (AI2C)

The AI2C is implementing the U.S. Army's Intelligence Strategy and partnering with industry, academia, and other Army units "to modernize the service's portfolio" by researching best practices to test AI systems for UGVs. It is currently researching the following areas and how they relate to AI-enabled UGVs [8]:

- Autonomy
- Human-AI Interaction
- Planning and Acting
- Decision Support
- Modeling
- Massive Data Management
- Devices and Computing

AI2C is also "conducting trials and evaluations of AI- and ML-based models" for use in UGVs [8].

2.3.2 Artificial Intelligence of Maneuver and Mobility (AIMM)

The AIMM program, run by the U.S. Army Combat Capabilities Development Command Army Research Laboratory in Adelphi, MD, is an essential research program (ERP) that supports the U.S. Army's Modernization Priority Next Generation Combat Vehicles (NGCV) "by developing novel autonomous capabilities for the NGCV Cross Functional Team's Robotic Technology Kernel." AIMM's ERP is comprised of three internal research thrusts [9]:

- Thrust 1, Learning for Mobility: Conducts foundational research and experiments using novel ML techniques to accelerate the ability of autonomous systems to move rapidly and robustly through complex terrain.

- Thrust 2, Context Aware Decision-Making: Improves autonomy in reconnaissance through context-aware perceptual processing, spoken dialogue for more efficient interaction with soldiers, and elaborate reasoning about mission context under time and resource constraints.

- Thrust 3, Tactical Behaviors: Enables autonomous systems to form cooperative dynamic teams to increase the speed, reliability, and scope of reconnaissance tasks by using autonomy to enable loose coupling of agents to overcome contested communication and uses reinforcement learning to develop new cooperative autonomous behaviors to deal with adversaries.

AIMM also has two external research programs: (1) the Scalable Adaptable Resilient Autonomy (SARA) Collaborative Research Alliance and (2) the Tactical Behaviors for Autonomous Maneuver (TBAM) Collaborative Research Alliance. The SARA alliance targets research gaps in the AIMM portfolio and collaborates with the "ARL autonomy software development ecosystem." The TBAM alliance "is a 6.1 basic research extramural program" focused on improving behaviors of AI agents in maneuvering in complex military environments [9].

Overall, AIMM's ERP aims to reduce soldier distractions on the battlefield through the integration of AI in Army vehicles and has a goal to construct an AI-enabled robotic combat vehicle that operates independently of the main combat vehicle [10]. In the long term, the program wants future combat vehicles to observe the context of the environment and obtain helpful clues for the soldier, requiring the AI to analyze complex, adversarial environments and develop a variety of courses of action [11].

2.3.3 Program Executive Office (PEO) Ground Combat Systems (GCS)

PEO GCS oversees "providing soldiers world-class affordable, effective, and sustainable ground combat equipment," which includes its Combat Vehicle Modernization Strategy. The mechanized combat vehicle (XM30) is a rapid prototyping acquisition intended to aid soldiers "seeking advantageous positions when involved in close combat" [12].

PEO GCS also works on the RCV program, mentioned in Section 2.2. The RCV software pathway program, overseen by PEO GCS, allows awarded contractors to "focus on software capabilities for autonomous mobility, user interface, platform control, and payload control" [12].

2.3.4 Adaptive Planner Parameter Learning From Demonstration (APPLD)

The U.S. Army Research Laboratory partnered with the University of Texas at Austin to develop an algorithm for UGVs. The algorithm will allow UGVs to "improve their own navigation systems by watching a human drive." Researchers used ML in tandem with classical autonomous navigation systems, which allowed APPLD to "improve an existing system in order to behave more like a human, rather than replacing the entire classical system." This creates a more flexible, adaptable system for varied military environments. APPLD has been tested on Army UGVs, and results showed that a trained APPLD system can "navigate the test environments more efficiently and with fewer mistakes compared to the classical system." Additional testing is needed, particularly in varied outdoor environments and when using different sensor information to help the algorithm "learn more complex behaviors" [13].

2.3.5 One Stop Systems (OSS) AI-Enabled Video Concentrator

Computing supplier OSS received a purchase order from the Army to design and manufacture an AI-enabled video concentrator for UGVs in the spring of 2024. The video concentrator will be used on Army ground vehicles, including the Stryker, Bradley, and Abrams combat vehicles. The video concentrator will be used for the 360° visualization system but can also be used for other AI purposes that "leverage sensor fusion, including threat detection, friend-or-foe identification, and natural-language processing for crew assist." Prototypes will be delivered by 2024, with vehicle applications and fielding planned to be completed in 2025 [14].

2.4 U.S. Marine Corps (USMC)

The USMC is also exploring ways to enable ground vehicles with AI capabilities. Research ranges from air to sea to land vehicles, and those programs with a ground vehicle element are discussed.

2.4.1 Marine Corps Warfighting Laboratory (MCWL)

One of the focus areas of the MCWL is AI, allowing for a handful of systems to be developed and tested for Warfighter use. The expeditionary modular autonomous vehicle (EMAV) is a "highly mobile, multipurpose" UGV created by the MCWL. It can "provide tactical-scale infantry support at the platoon level" while offering "precise fire effects." The EMAV can avoid obstacles and "enables the integration of command, control, communications, computers, intelligence, surveillance and reconnaissance; electronic warfare systems [and] other weapons, as well as platform systems such as lethality, automotive or power distribution" [15]. It allows the USMC to quickly switch payloads and/or weapons.

2.4.2 Intelligent Robotics and Autonomous Systems (IRAS)

The IRAS is not solely focused on UGVs but uses a range of air, surface, and land "logistical connector vehicles [to] enable ship-to-ship sustainment of maneuvering units," lowering the risk to manned resupply vehicles. Software developments in AI and ML organize data in a systematic, prioritized way, increasing the survivability of marine sensors that can "detect the enemy throughout the electromagnetic spectrum," allowing operators to quickly close kill webs and destroy a target [16].

2.4.3 U.S. Marine Forces Special Operations Command

The U.S. Marine Forces Special Operations Command tested a quadrupedal UGV with AI-enabled rifles. Two Vision 60 UGVs from Ghost Robotics have been fitted with an AI-enabled gun system. The rifle system uses an "AI-assisted digital imaging system" to detect targets while awaiting human authorizations to engage. The robot also includes an X360 Pan/Tilt Gimbal stack for electro-optical/infrared to scan objects, vehicles, and even people, while relaying information back to a human user. Having a smaller, quadrupedal UGV allows operations to occur in "tight spaces such as tunnels and trenches" and offers the option for use in clearing mined areas, minimizing risk to soldiers [17].

2.5 U.S. Navy

The Navy Center for Applied Research in Artificial Intelligence is a program run by the U.S. Naval Research Laboratory (NRL) and focuses on developing [18]:

- Adaptive systems for all types of autonomous vehicles
- Intelligent systems for all types of autonomous vehicles
- Interactive systems for all types of autonomous vehicles
- Perceptual systems for all types of autonomous vehicles

While a specific program for AI-enabled UGVs is not specifically mentioned, the group has been included due to the potential the research can have in the area.

Another NRL program, the Laboratory for Autonomous Systems Research, focuses on creating small UGVs using "a motion capture system [that] allows tracking and [enables gathering] of high-accuracy ground truth data of up to 50 objects" [19].

References

[1] Thompson, M. "AI-Enabled Ground Combat Vehicles Demonstrate Agility and Synergy at PC21." U.S. Army, https://www.army.mil/article/251632/ai_enabled_ground_combat_vehicles_demonstrate_agility_and_synergy_at_pc21, 1 November 2021.

[2] Keller, J. "Peraton Labs to Help Develop Artificial Intelligence (AI) and Machine Learning for Unmanned Ground Vehicles." Military Aerospace Electronics, https://www.militaryaerospace.com/computers/article/14302038/artificial-intelligence-ai-machine-learning-unmanned, 30 November 2023.

[3] Young, S. H. "Robotic Autonomy in Complex Environments with Resiliency." DARPA, https://www.darpa.mil/program/robotic-autonomy-in-complex-environments-with-resiliency, accessed on 18 September 2024.

[4] Bisht, I. S. "DARPA to Field Test Autonomous Military Off-Roader." *The Defense Post*, https://www.thedefensepost.com/2022/01/18/darpa-test-auto-off-roader/, 18 January 2022.

[5] Defense Advances Research Projects Agency. "RACER Speeds Into a Second Phase With Robotic Fleet Expansion and Another Experiment Success." DARPA, https://www.darpa.mil/news-events/2024-04-23, 23 April 2024.

[6] Defense Innovation Unit. "Accelerating Autonomous Vehicle Technology for the DoD." https://www.diu.mil/latest/accelerating-autonomous-vehicle-technology-for-the-dod, 3 April 2024.

[7] Kodiak Robotics. "U.S. Department of Defense Awards $50 Million Contract to Kodiak Robotics for Autonomous U.S. Army Ground Reconnaissance Vehicles." PR Newswire, https://www.prnewswire.com/news-releases/us-department-of-defense-awards-50-million-contract-to-kodiak-robotics-for-autonomous-us-army-ground-reconnaissance-vehicles-301695349.html, 6 December 2022.

[8] Pereira, F. C. "U.S. Army Has 'Lot of Work' to do to Push AI in Ground Vehicles: Official." *Breaking Defense*, https://breakingdefense.com/2023/08/us-army-has-lot-of-work-to-do-to-push-ai-in-ground-vehicles-official/, 15 August 2023.

[9] U.S. Army Combat Capabilities Development Command Army Research Laboratory. "Artificial Intelligence of Maneuver and Mobility (AIMM)." DEVCOM, https://arl.devcom.army.mil/what-we-do/aimm/, accessed on 18 September 2024.

[10] Park, S. "Army Researchers Augment Combat Vehicles With AI." DVIDS: Defense Visual Information Distribution Service, https://www.dvidshub.net/news/373414/army-researchers-augment-combat-vehicles-with-ai, 25 June 2020.

[11] U.S. Army Combat Capabilities Development Command Army Research Laboratory Public Affairs. "Army Researchers Augment Combat Vehicles With AI." U.S. Army, https://www.army.mil/article/236733/army_researchers_augment_combat_vehicles_with_ai, 25 June 2020.

[12] U.S. Army. "U.S. Army Acquisition Program Portfolio 2023–2024." https://api.army.mil/e2/c/downloads/2023/11/20/0f0da2ca/2023-u-s-army-acquisition-portfolio.pdf, accessed on 18 September 2024.

[13] McFarland, A. "U.S. Military Getting Closer to Autonomous Off-Road Combat Vehicles." Unite AI, https://www.unite.ai/u-s-military-getting-closer-to-autonomous-off-road-combat-vehicles/, 9 December 2022.

[14] Daigle, L. "AI-Enabled Rugged 360-Degree Video Part From OSS Gets U.S. Army Order." Military Embedded Systems, https://militaryembedded.com/ai/cognitive-ew/ai-enabled-rugged-360-degree-video-part-from-oss-gets-us-army-order, 3 April 2024.

[15] Underwood, K. "Robots Lighten the Load for Marines." Signal, https://www.afcea.org/signal-media/robots-lighten-load-marines#:~:text=One%20key%20robotic%20system%20for,and%20offers%20precise%20fires%20effects, 1 December 2018.

[16] Chirhart, K. "Intelligent Robotics and Autonomous Systems." Marines, https://www.marines.mil/News/News-Display/Article/3436190/, 21 June 2023.

[17] Saballa, J. "U.S. Marines Test Robot Dogs with AI-Enabled Rifles." *The Defense Post,* https://thedefensepost.com/2024/05/09/us-marines-robot-dogs/, 9 May 2024.

[18] U.S. Naval Research Laboratory. "Navy Center for Applied Research in Artificial Intelligence (NCARAI)." https://www.nrl.navy.mil/itd/aic/, accessed on 18 September 2024.

[19] U.S. Naval Research Laboratory. "Laboratory for Autonomous Systems Research." https://www.nrl.navy.mil/lasr/, accessed on 18 September 2024.

Biography

Taylor H. Knight is the technical lead of the Defense Systems Information Analysis Center (DSIAC). She provides technical consultation and support for products and services produced by DSIAC associated with 10 defense-related technical focus areas (TFAs). Prior to the position, Mrs. Knight was a research analyst with DSIAC and provided research efforts across DSIAC's TFAs. She has authored dozens of scientific and technical reports on defense-related topics, with a focus on hypersonics and unmanned aerial vehicles. Mrs. Knight holds an M.S. in human resources development, instructional leadership and a B.S. in education, with a minor in biology and Spanish.