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AUTONOMY AT SCALE

Intelligent Machines Advancing Technology to Improve our Future

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USE CASE: ADVERSARIAL ENVIRONMENTS

Daniel Yim & Thomas Mitchell

The expansion of autonomous technology into hostile environments derives from many years of research. Inventions such as the Whitehead Torpedo in 1868, the Mechanical Mike aircraft autopilot in 1933, Tsukuba Mechanical Engineering in 1977, VaMoRs in 1987, General Atomics MQ-1 Predator in 1995, and the various Defense Advanced Research Projects Agency (DARPA) challenges from 2004 through 2013[1] have helped tackle situations in hostile environments that we see today.

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Autonomous systems have demonstrated that they can significantly increase both the operational capabilities and the safety of our modern-day military and civilian sector in the United States. Depending on the level listed under "Levels of Future Combat Systems", the autonomous system required for the mission, may or may not have humans as the deciding factor. Autonomy in these circumstances leads to ethical questions such as how the autonomous system would follow the laws of war established by the Geneva Convention. One such question already arose in 2008, when Ron Arkin wrote a technical report for the U.S. Army Research Office on creating an "ethical governor" for autonomous weapons[2]. The ability for autonomous machines on the battlefield to maintain a set of ethics in warfare is a key aspect of the discussion surrounding this issue.

History of Autonomy in the Military and Defense

The bombardiers of World War II could not hit military targets precisely and avoid civilians if they wanted to; the bombs simply were not accurate as compared to today's standards[3]. Spending on research of uninhabited aircraft, or drones, was around $300 million per year in the 1990s. By 2005, the Department of Defense's (DoD's) uninhabited aircraft spending increased six-fold to over $2 billion per year. In Iraq and Afghanistan, drones provided military personnel the ability to surveil terrorists while not risking human lives. Uninhabited aircraft gave the commanders a low-cost and low-risk way to place eyes in the sky. Due to the success of uninhabited aircraft tactics, the DoD started in early 2005 to develop and publish different roadmaps for the future of unmanned autonomous systems. These roadmaps, with an outlook of about 20 years into the future, described the needs of the DoD—sensors, communications, power, and weapons with autonomous systems—while informing the industry.

Differences in the Research of Autonomous Systems

Autonomy scales defined by the DoD for the Navy, Air Force, and Army demonstrate the different focuses of research in autonomous systems of each military branch based on its mission. The military's research differs from industry because of the complexity of missions that would be assigned to the autonomous vehicle or system. The figures below demonstrate and compare the different areas of the military branches.

In 2011, the roadmap published by the DoD stated, "For unmanned systems to fully realize their potential, they must be able to achieve a highly autonomous state of behavior and be able to interact with their surroundings. This advancement will require an ability to understand and adapt to their environment, and an ability to collaborate with other autonomous systems"[4]. The DoD realized that producing tens of thousands of drones was not a sufficient strategy. They would need to train the service members to use and operate the drones—requiring a large investment of time and budget. The DoD then released its 2011 roadmap that stated, "autonomy reduces the human workload required to operate systems, enables the optimization of the human role in the system, and allows human decision making to focus on points where it's most needed. These benefits can further result in manpower efficiencies and cost savings as well as greater speed in decision making"[5].

This DoD robotic roadmap describes four different levels of autonomy: 1) human operated, 2) human delegated, 3) human supervised, and 4) fully autonomous.

Figure 1: A study released on "Autonomous Vehicles in Support of Naval Operations"[6] identified three types of naval autonomous systems useful to the Department of the Navy: scripted, supervised, and intelligent.

LEVELS OF FUTURE COMBAT SYSTEMS7[7]

While the Air Force conducted their research with DARPA, the Army created the Future Combat System Program. The Army wanted to scale different levels of autonomy for its missions in hostile environments. The table below displays the research conducted for the 10 different levels of autonomy for autonomous systems.

Level	Description	Observation	Decision Ability	Capability	Example
1	Remote control	Driving sensors	None	Operator steering commands	Remote control vehicle or car
2	Remote control with vehicle state knowledge	Local pose	Reporting health and state of the vehicle	Remote operator steering commands, using vehicle state knowledge	Teleoperation with operator knowledge of vehicle pose situation awareness
3	External preplanned mission	World model database-basic perception	Autonomous Navigation System (ANS) - commanded steering based on externally planned path	Path following with operator help	Lane assist
4	Knowledge of local and planned path environment	Perception sensor suite	Local plan/re-plan -world model correlation with local perception	Follower with operator help	Remote path following, convoying
5	Hazard avoidance or negotiation	Local perception correlated with world database	Path planning based on hazard	Semiautonomous navigation, operator intervention	Basic open and rolling terrain
6	Object detection, recognition, avoidance or negotiation	Local perception and world model database	Planning and negotiation or complex terrain and or objects	Rolling terrain with obstacle negotiation, limited speed, with some help from operator	Robust, open, terrain with obstacle negotiation
7	Fusion of sensors and data	Local sensor fusion	Robust planning and negotiation of complex terrain, environmental conditions, hazards, and or objects	Complex terrain with obstacle negotiation, limited speed, and operator help	Complex terrain
8	Cooperative operations	Data among cooperative vehicles	Advanced decisions based on data from other vehicles	Robust, complex terrain with full mobility and speed. Autonomous coordinated group	Coordinated autonomous systems in complex terrain
9	Collaborative operations	Fusion between ANS data, surveillance, target acquisition	Collaborative reasoning, planning and execution	Accomplishment of mission objectives with collaborative planning and execution, with operator oversight	Autonomous mission, with individual goals with little supervision
10	Full autonomy	Data from all participating assets	Independence to plan and implement to meet objectives	Collaborative planning and execution, with operator oversight	Autonomous mission without supervision

Table 1: Future Combat Systems, adapted from Office of the Assistant Secretary of the Army.

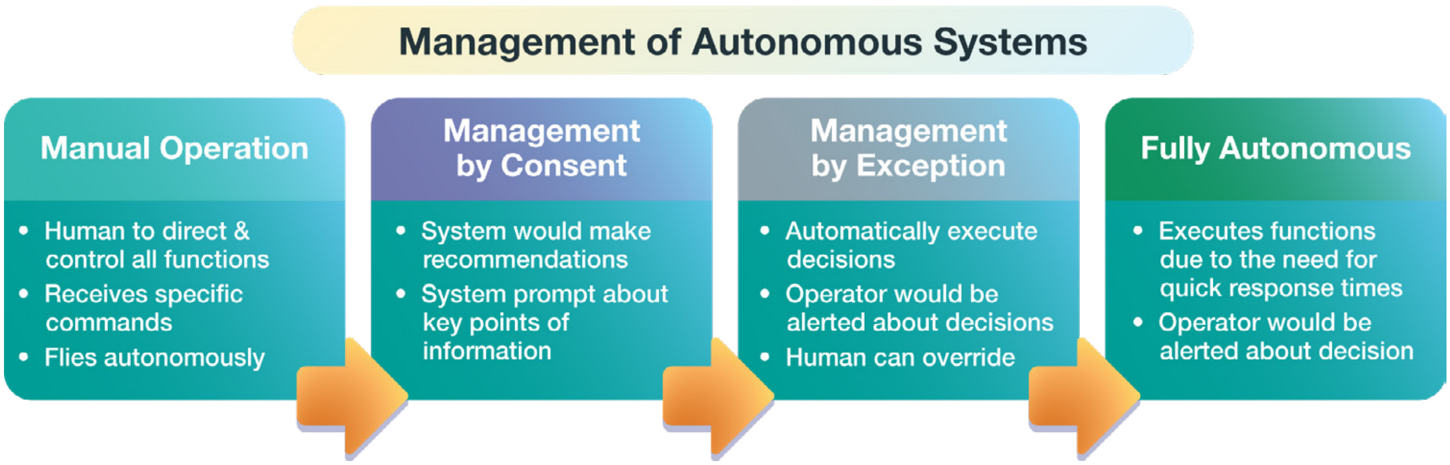

Figure 2: Autonomy scales defined by the joint effort between DARPA and the Air Force – "Autonomy Vehicles in Support of Naval Operations"[6] published in 2005 established four different levels of autonomy for uninhabited combat aircrafts.

The research conducted by the DoD led the private sector to make great advancements in the field. From the 1990s to today, the United States has chased the next level of autonomy on the horizon—leading to our current capabilities and offering the potential for advancement in emerging autonomous technologies.

Hostile environments

Autonomy at scale and the use of autonomous systems in hostile environments has been part of military and civilian conversations. Significant interest has emerged in how autonomy can be used to combat different hostile scenarios, such as bomb disposal, deep ocean, hazardous materials (HAZMAT), warfighting, and active shooters. Autonomous systems can be used to access environments too dangerous for human exploration—offering greater access to intelligence in hostile environments while reducing risk to life. As the research has progressed, systems that required close human supervision to function now possess capabilities to operate under minimal human supervision.

Before autonomous systems were used to disarm a bomb, a technician wearing a protective suit, with flame and fragmentation resistant material similar to a bulletproof vest, would need to operate in close range of the device. Now that technology has improved, autonomous systems can disarm bombs—keeping the human operators out of harm's way. These technologies have been applied in hostile situations such as countering terrorists with car bombs.

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With jutting reefs, sloping sand dunes, and large rocks, the seafloor remains one of the most challenging environments presenting daunting challenges to researchers. The ocean at a given location may be murky enough to complicate perception, search, and object recognition. Research efforts in this environment have benefited greatly from the application of advanced autonomous systems. Commenting on its work with DARPA, MIT researcher Professor Schmidt said, “We present the acoustic environment and the oceanographic environment very accurately on-board, combining sensor data with modelling and then using that in the decision making. Five years ago, we didn’t have the possibility of putting these kinds of models and predictions on board the vehicles—computer technology wasn’t small or efficient enough”[8]. The success of autonomous systems in the ocean environment has sparked interest in creating autonomous ships that could seek and destroy sea mines. This technology has the potential to improve safety across our seas, opening more navigable routes.

Current and Emerging Technologies

Current and emerging technologies in autonomy have drastically improved—from a preprogrammed robot instructed to conduct assigned tasks to autonomous systems that can detect their surroundings from sensor information and then act to avoid objects. Both industry and the public sector have shifted focus to fielding practical robots capable of re-planning their routes or mission in response to changing circumstances. These technological advancements have yielded real-world applications such as the use of drones to detect leaks along a pipeline, the integration of machine learning of connected devices, and integration of computer vision.

Technology in autonomous systems for bomb removal and detection has advanced over the past two decades. Qinetiq North America created a tactical robot[9] that has been in use since 2000. This autonomous robot, called TALON, maps hostile environments, disarms bombs, and can provide assistance in situations involving HAZMAT. It can detect radiation, volatile gases, and traces of explosives. The TALON is an example of autonomous systems saving lives in hostile environments.

To answer the challenges posed by deep ocean scenarios, OceanAlpha created the unmanned surface vehicle (USV), a small boat that could be used to swarm a large ship if necessary. Each of the small boats would communicate with each other and then back to a mothership that would control these vessels. USVs would be able to swarm in maritime combat, making them easy to deploy against enemies with reduced risk to military personnel. The USV uses a 5G connection to communicate among vessels and complete missions. This technology could be applied in maritime conflicts, such as combating pirates attacking container ships[10].

Drones are also being deployed increasingly for emergency response in times of disaster[11]. Finnish tech firm Nokia has been researching the abilities of drones to provide instant 4G mobile network coverage during a disaster. AT&T used a flying “Cell on Wings” (COW) to provide emergency 4G coverage in Puerto Rico after Hurricane Maria struck the island in 2017. Each COW can cover 36 square kilometers and enable critical communication in a disaster scenario. Drones can also enable our fire and police services to see real-time video of a fire or incident, while the fire truck or police cruiser acts as the command center.

In addition to these private sector developments, the U.S. Military has deployed UGVs for the battlefield with the ability to collect information using sensors to create maps of building interiors and the landscape surrounding them. They can also detect objects like people and other vehicles. UGVs can work for extended hours any time of day—providing military personnel with the data, when it is needed to make critical mission decisions. If military personnel encounter explosives, UGVs can disarm and/or remove them. This capability reduces the military's risk of losing soldiers on the battlefield. If damaged, the UGV can even repair itself without intervention (depending on the extent of the damage). They can aslo transport military personnel between waypoints. UGVs are another example how autonomous systems can keep humans safe and out of harm's way.

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Potential Benefits and Impacts

As we transition into the fourth industrial revolution, an increase in economic productivity will depend on how well we leverage modern technology such as Internet of Things (IoT) platforms, location detection technology, advanced human-machine interfaces, and smart sensors. The common theme among these technologies is computing intelligence, which can be applied to benefit most human endeavors. Many repeatable tasks currently carried out by humans will soon be done by machines, and this will be even more so the case for tasks that have historically been dangerous.

Like UGVs, unmanned aerial vehicles (UAVs) currently support the U.S. Navy in various reconnaissance missions in high-altitude and long-endurance environments. UAVs can be catapulted off and land on aircraft carriers for an increased level of capability in combat. While reconnaissance missions aren't considered direct combat operations, using UAVs to collect imagery and data about enemy forces in hostile environments is vital to any mission. Remotely operated unmanned systems also give human operators the ability to achieve the same or even greater results while physically situated in a safer location, not directly exposed to enemy threats.

Resource management is at the heart of operations in hostile environments. The operational productivity of military organizations will likely see improvement as these autonomous systems save lives. Military personnel can focus their expertise and skillsets as operators of autonomous systems or in areas where machines cannot assist.

Challenges

As with all technology solutions, autonomous machines—specifically those used in hostile environments—present challenges. These challenges include the ethical questions, surrender situations, and the limitations of autonomous systems. Interestingly, interoperation of autonomous machines can help address many of the challenges, but increased connectivity also has the potential to create additional challenges in the foreseeable future.

The ethical dilemma is noteworthy: machines do not have empathy towards humans. An autonomous machine would not be able to make any decisions based on its "feelings" about the situation. This presents a significant dilema if machines overtake humans as decision makers in hostile environments. The machine may not be able to distinguish between an enemy combatant and an innocent civilian. The United Nations passed a resolution concerning the use of autonomous systems for combat in a war zone, ruling that if used, a human must be present to make a lethal decision. This resolution represents an important step toward preventing lethal machines from making lethal decisions.

How an autonomous system reacts in a surrender situation also represents a challenge. The autonomous machine cannot discern whether an enemy is attempting to surrender. A human might not fire upon someone who has surrendered, but an autonomous machine could potentially make a lethal decision based on orders.

The limitations of the sensors and software installed present another challenge with autonomous machines. If a sensor was damaged, it could send false positives or negatives to the central processing unit (CPU) of the machine. With that false information, the decisions the machine makes would become skewed. Software is also susceptible to bugs, system flaws, and malicious attacks that could affect the movements, sensor readings, and decisions of an autonomous vehicle.

Conclusion

Despite the many challenges, autonomy at scale presents a world of benefit and opportunity in operation in hostile environments. On the battlefield or in a disaster zone, autonomous systems with the appropriate guidance and controls, offer significant potential to improve resource efficiency and reduce costs. Perhaps their greatest potential benefit, though, will be the human lives that can be saved.

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703.610.2000 answers@noblis.org @NoblisInc