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The Pentagon's Robots: Arming the Future

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Robots have stepped out of the science fiction pages and onto the battlefield. Thousands are deployed in Iraq and Afghanistan, supporting military operations on land, at sea, and in the air. Some robots cost as little as several thousand dollars each. Controlled remotely by soldiers, sailors, and airmen, they perform tasks such as disarming roadside bombs, scouting dangerous territory, and patrolling the sky.

As technology advances, robots will become increasingly autonomous of human supervision, providing new cutting-edge national security applications that could give the U.S. military significant competitive advantages. Robots on the battlefield will not bring an age of "bloodless" push-button warfare nor provide "silver-bullet" solutions to every combat challenge, but they can offer U.S. forces tactical advantages for outfighting both conventional (regular armed forces) and unconventional (e.g., terrorists and insurgents) enemies.

The U.S. government should continue prudent investments in robotic technologies, particularly for autonomous operations—an area of research not adequately supported by commercial research and development. Congress can help by establishing a framework that will facilitate national security research and development programs and by addressing concerns about the risk to humans with legislative guidelines for liability and safety issues in research, development, and procurement.

When the Future Arrives

The challenge of imagining the future of war is often a question of timing. Promising technologies are

Talking Points

- Thousands of robots are currently deployed in Iraq and Afghanistan, supporting military operations on land, sea, and air. Controlled remotely by soldiers, sailors, and airmen, they perform tasks such as disarming roadside bombs, scouting dangerous territory, and patrolling the sky.
- Robotic technology is moving toward more autonomous action, enabling robots to sense, react, and even make decisions on their own. These capabilities will allow robots to perform such battlefield tasks as ferrying supplies when and where needed, helping soldiers make critical decisions with the most up-to-date intelligence, and even engaging in combat.
- America's capability to seize and maintain a strategic advantage in robotic national security applications could be lost without sustained and focused commitment from the Administration and Congress.
- Congress should ensure adequate funding, encourage increased coordination, and craft policies that encourage prudent investment in robotic technology.

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often derided or dismissed simply because their proponents' imaginations outpace the capacity of science and technology to deliver.

World War I offers a case in point. The nascent technologies described by 19th century science fiction writers and military futurists were not ready for prime time and incapable of breaking the gridlock of attrition warfare. While H. G. Wells and Jules Verne are often praised for their foresight in envisioning the proliferation of weapons like tanks, airplanes, and submarines, the machines that they described were little more than fanciful, completely out of the reach of foreseeable technologies. Military writers were more conservative in their appreciation of how machines would change warfare, but even they missed the mark.[1]

In World War I, the future arrived too fast, before new technologies had matured to the point that they could reshape the face of conflict. If World War I had been avoided and the great powers had not tested these new technologies until the 1940s when they were more mature, both science fiction writers and military futurists might have been much closer to making more accurate guesses.

Timing may not be everything, but it can dramatically affect the process of turning imaginative vision into reality. This may turn out to be the case for robotics. The vision of robots in combat, popularized in science fiction since the cliffhanger movie serials of the 1930s, never came to fruition in the succeeding decades. The Pentagon had little to show after decades of research, leading the promise of robotics in battle to be largely derided and dismissed as a failure of overly exuberant imagination.

Dismissing military robotics as a failed future vision may be premature. The armed services' increasing expertise in robotic technologies, the effectiveness of robots in recent military operations, and promising new research developments suggest that artificial warriors may yet prove to be the next big thing.

The Pentagon's New Weapons

After decades of military research and development, robotic technologies have finally matured to where they present significant national security applications. Their effectiveness is most noticeable in environments that are ill-suited to manned warfare.

Robots have proven most efficient and cost-effective in combat tasks involving the three Ds—dull, dirty, and dangerous. Dull assignments are those that require routine functions such as monitoring a bridge crossing site. Dirty jobs are performed in harsh environmental conditions, such as searching contaminated areas. Dangerous missions involve tasks in which humans could suffer physical harm, such as disarming an improvised explosive device (IED). Currently, the U.S. military employs three different robotic platforms for three-D operations:

Unmanned Aerial Vehicles. Unmanned aerial vehicles (UAVs) have emerged as the most frequently employed robotic platform on the battlefield. Ironically, the failure of numerous programs during the Cold War initially earned them the reputation of "'vampires' of military acquisition," "sucking" up research and development dollars without delivering any practical utility. That began to change when UAVs first proved their effectiveness during the first Gulf War (1991) "when the low-tech, short-range Pioneer [short-range reconnaissance drone resembling a large model airplane]," as J. R. Wilson points out, "helped to identify artillery and naval gun targets, detected high-speed Iraqi patrol boats, and even became the first 'robot' to which enemy combatants surrendered."[2]

Throughout the 1990s, all of the military services developed new applications for UAVs. Many of the new capabilities were battle-tested in combat operations in Bosnia, Kosovo, Afghanistan, and Iraq. Today, over 700 types of UAVs support U.S. military forces.[3] The armed services employ about 3,000 individual UAVs in Iraq alone.[4]

1. Antulio J. Echeverria II, *Imagining Future War: The West's Technological Revolution and Visions of Wars to Come: 1880–1914* (Westport, Conn.: Praeger Security International, 2007), pp. 95–96.
2. J. R. Wilson, "A New Generation of Unmanned Aircraft," *Aerospace America*, January 2007, at *www.aiaa.org/aerospace/images/articleimages/pdf/AA_Jan07_WIL.pdf* (August 9, 2007).
3. *Ibid.*

The Predator—a medium-altitude, long-endurance, remotely piloted aircraft—stands out as the most notable UAV in military service. Initially used for reconnaissance, the Predator has also been armed with Hellfire air-to-ground missiles and has been used to conduct combat missions in Iraq and Afghanistan. Other UAVs range from the hand-launched Raven, used by ground troops, to Global Hawk, a high-altitude, long-range, long-endurance platform with a wingspan as wide as a commercial airliner that can conduct surveillance missions anywhere in the world.

UAVs are being used more heavily because of their increasing capacity to loiter over the battlefield for a long time and provide a persistent presence. For example, the Predator B can stay airborne for a day or more. The current generation of UAVs can track specific targets for extended periods and can attack the target or relay information to ground troops. Insurgents in Iraq have become so wary of UAVs that they are reluctant to loiter in any open place for more than a few minutes. Both Americans and their enemies now see UAVs as a ubiquitous presence on the battlefield.

Unmanned Underwater Vehicles. The Navy is developing unmanned underwater vehicles (UUVs) to hunt and destroy sea-based mines. Remus, a three-foot-long robot that can detect mines underwater, is being retrofitted with an explosive charge so that it can attach itself to and detonate underwater bombs and mines. Remus also carries a sensor payload that allows it to identify entities in the surrounding waters.

The Navy has tested Remus in real missions, using the robot to clear mines in the port of Um Qasr, Iraq, in 2003. Remus robots searched nearly a square-mile area and removed a number of mines in 16 hours. Divers would have needed 21 days to complete the same mission.[5]

Unmanned Ground Vehicles. Unmanned ground vehicles have played a critical role in combating IEDs, the deadliest weapon used against U.S. troops in Iraq. Roadside bombs have accounted for more than 70 percent of U.S. casualties.[6] The Pentagon's Joint Robotics Program, established in 1990 to oversee robotics technologies, established a plan to acquire "small, man-portable robotics systems" equipped with explosives ordnance disposal (EOD) tools that would be "fielded as quickly as possible to assist EOD forces in the mission to defeat IEDs."[7]

Initially deployed to Afghanistan to search caves for weapons caches, the first small unmanned ground vehicles (SUGVs) arrived in Iraq in April 2004. One of the early SUGV models was the PackBot, a 30-pound robot that is small enough to fit in a backpack. It is also extraordinarily rugged. A PackBot can be thrown from the second story of a building and still work. PackBot has recently been equipped with a manipulator arm with a two-meter reach and a camera that allows the operator to remotely identify and disarm bombs.

Today, SUGVs are integral to ground operations. According to press reports, the military has deployed "nearly 5,000 robots in Iraq and Afghanistan, up from 150 in 2004…. Soldiers use them to search caves and buildings for insurgents, detect mines, and ferret out roadside bombs."[8] By the end of 2005, robots reportedly had rendered safe or exploded more than 1,000 IEDs.[9]

In addition to their utility, SGUVS are relatively inexpensive compared to other robots. Predators cost between $4.5 million and $8.3 million each, UUVs about $5.5 million, and PackBots between $80,000 and $150,000.[10] This low cost has enabled rapid procurement, deployment, and adoption of ground-based robots.

4. Tim Mahon, "In Harm's Way: New Missions, Technology Shape UAV Combat Tactics," *C4ISR*, October 2006.
5. Associated Press, "Military Increasingly Looking to Robots to Clear Waterways of Dangerous Mines," *International Herald Tribune*, July 27, 2007, at *www.iht.com/articles/ap/2007/07/27/america/NA-GEN-US-Mine-Destroying-Robots.php* (August 14, 2007).
6. Associated Press, "Explosive-Sniffing Robots Headed to Iraq to Help U.S. Military Counter Deadly Roadside Bombs," *Niagara Gazette*, March 29, 2007, at *www.niagara-gazette.com/newtoday/gnnnewtoday_story_088144250.html* (August 9, 2007).
7. *Ibid.*, pp. 20–21.
8. Associated Press, "Explosive-Sniffing Robots Headed to Iraq."
9. *Ibid.*

Empowering New Systems

Currently deployed robots are teleoperated, meaning that a human must direct their every move. However, robotic technology is moving toward more autonomous action. Autonomy will enable robots to sense, react, and even make decisions without human intervention. On the battlefield, these capabilities will transform robots from adjunct assets to independent combat platforms that can ferry supplies, search out and interpret intelligence for soldiers, make critical decisions with the most up-to-date information, guard roads and supplies, hunt enemy forces, and even engage in combat.

To achieve autonomy, research is focusing on three core aspects: sensors, cognition, and networking.

Sensing the Environment. Sensors allow robots to observe the world around them. Many robot designs use sonar, laser range finders, television cameras, and microphones. For example, the Massachusetts Institute of Technology and the Naval Research Laboratory are conducting extensive research into map-creation by robots to enable them to guide themselves.[11] A NASA laboratory is investigating the use of infrared sensors on a flexible outer body, allowing the robot to sense objects in its path.[12] Researchers at the University of Nebraska are developing a system to give a robot a sense of touch that equals that of the human finger.[13] These efforts are only a few of the entire spectrum of projects being undertaken by government and university research centers.

To encourage the development of self-guiding systems, the Defense Advanced Research Projects Agency (DARPA) has established the Grand Challenge, a competition for robotic vehicles. The goal of the race is to identify technologies that will enable robots to navigate complex terrain autonomously over a long distance. In the first Grand Challenge in 2004, not a single team completed the 150-mile course. The most prevalent difficulty was the robots' inability to navigate around detected obstacles while maintaining their GPS-derived locations. In the 2005 race, participants were able to surmount this critical problem. Six vehicles completed a 132-mile course. In November 2007, DARPA sponsored a 60-mile contest in an urban environment.[14]

Cognitive Action. To streamline robot–human interactions, researchers must develop machines capable of reasoning like human beings.[15] Autonomous robots must be capable of learning and making decisions. In dealing with humans, the robot will need not only to reason, but also to have cognitive skills, such as being able to follow an ambiguous order that requires intuitively understanding what the command means.

Evolutionary robotics is a newly emerging field of robotic design in which a machine system works out a solution and then repeats the process until the robot determines the most efficient process. The solution then guides the control system in operating the robot's physical attributes, such as walking.[16] Such innovations may presage the deployment of autonomous robots.

10. Strategy Page, "Buying Predator Bs," February 8, 2006, at *www.strategypage.com/htmw/htproc/articles/20060208.aspx* (August 15, 2007); "2 REMUS 600 Systems for UK Royal Navy," *Defense Industry Daily*, September 23, 2007, at *www.defenseindustrydaily.com/2-remus-600-systems-for-uk-royal-navy-03860* (October 4, 2007); and Kris Osborn, "U.S. Wants 3,000 New Robots for War," *Defense News*, August 13, 2007, at *http://defensenews.com/story.php?F=2956107&C=thisweek* (August 14, 2007).
11. John J. Leonard, speech at program on "Robots: The Future is Here," audio file, The Heritage Foundation, June 5, 2006, at *www.heritage.org/Press/Events/ev060506a.cfm* (December 13, 2007), and U.S. Naval Research Laboratory, "Natural Interface and Control for a Segway RMP Robot," at *www.nrl.navy.mil/aic/iss/aas/SegwayRMP.php* (June 19, 2006).
12. Lori Keesey, "High-Tech Robot Skin," National Aeronautics and Space Administration, May 11, 2005, at *www.nasa.gov/vision/earth/everydaylife/vladskin.html* (June 6, 2006).
13. Rebecca Morelle, "Robot Device Mimics Human Touch," BBC News, June 8, 2006, at *http://news.bbc.co.uk/2/hi/science/nature/5056434.stm* (June 12, 2006).
14. Press release, "DARPA Announces Third Grand Challenge: Urban Challenge Moves to the City," U.S. Department of Defense, Defense Advanced Research Projects Agency, May 1, 2006, at *www.darpa.mil/grandchallenge/docs/urb_challenge_announce.pdf* (June 23, 2006).
15. John Bluck, "NASA Developing Robots with Human Traits," National Aeronautics and Space Administration, May 24, 2005, at *www.nasa.gov/vision/universe/roboticexplorers/robots_human_coop.html* (June 19, 2006).

To maintain a level of control over autonomous robots, the military services are investigating "variable autonomy," combining aspects of autonomy and human control.[17] The Naval Research Lab is researching human control of robots through voice commands and hand movements.[18]

Network-Friendly. It is essential for robots to communicate and work together with the surrounding humans. In 2001, the Pentagon released the Joint Architecture for Unmanned Systems protocols to standardize communications software for unmanned systems. With these standards, systems can be configured to match a variety of human–machine environments in which robots, soldiers, civilians, and enemy combatants may share the same battlespace.

Developers of the Army's Future Combat Systems (FCS) are using the Joint Architecture for Unmanned Systems to develop interoperable programming for FCS robotic platforms. Robots will be operated under an umbrella of systems that will manage FCS, including the Warfighter Information Network-Tactical (WIN-T). Under WIN-T's Joint Tactical Radio and Ground Mobile Radio systems, soldiers and robots will be able to communicate via software networks that provide multichannel voice, data, imagery, and video communications.[19]

The Next Generation

Autonomous robots are closer to real combat capabilities. The Army will soon field the Mobile Detection Assessment Response System (MDARS), a semi-autonomous security-guard robot. This nine-foot, 3,500-pound robot can travel up to 20 miles per hour using inertial and satellite navigation and can scan the surrounding environment with radar and infrared beams. Using its on-board sensors, MDARS will able to conduct independent patrol or sentry duty, avoiding obstacles and detecting intruders up to 300 meters away.[20]

The Army is also developing the semi-autonomous Multifunctional Utility Logistics and Equipment (MULE) vehicle, a six-wheeled, 20-foot robot that can autonomously traverse rugged terrain, carrying 1,900 pounds of equipment.[21] MULEs will perform convoy operations and support ground assaults. Currently, one-fourth of the planned systems for FCS will be robotic, including both remotely piloted air and ground vehicles.[22]

The Navy recently tested two UUVs as part of the Long Term Mine Reconnaissance System. Submerged submarines launched and recovered the vehicles through their torpedo tubes.[23] MANTA, a proposed underwater system, would detach itself from a submarine's hull and be able to deploy torpedoes or small UUVs. These remote robots and weapons could extend a submarine's range into shallow waters that the boats cannot traverse.[24]

In the air, prototypes for fully autonomous UAVs are being developed. In August 2005, Boeing Corporation successfully tested two X-45A unmanned combat aerial vehicles (UCAVs). In these tests, the two X-45As took off, planned a route, evaded threats, and reached a designated target.[25] One recent study concluded that UCAVs offer significant potential for extended operations at long range.[26]

16. Andrew Nelson, "Evolutionary Robotics," at *www.evolutionaryrobotics.org* (June 23, 2006).
17. U.S. Army Research Laboratory, "Robotics Alliance," modified July 28, 2006, at *www.arl.army.mil/main/Main/default.cfm?Action=93&Page=156* (June 16, 2006), and U.S. Naval Research Laboratory, "Adaptive Systems," at *www.nrl.navy.mil/aic/as/index.php* (September 25, 2007).
18. U.S. Naval Research Laboratory, "Human/Robot Interaction," at *www.nrl.navy.mil/aic/iss/aas/IntelligentHumanRobotInteractions.php* (October 17, 2007).
19. Doug Beizer, "Talk About an Evolution," *Washington Technology*, August 6, 2007, at *www.washingtontechnology.com/print/22_14/31155-1.html* (August 29, 2007).
20. Kris Osborn, "Army Set to Field Autonomous Security-Guard Robot at Bases," *Marine Corps Times*, July 16, 2007.
21. Kris Osborn, "Multitask MULE: Semi-Autonomous Robot Moves, Fights, Transports with Troops," *Defense News*, April 30, 2007.
22. U.S. Army, "Future Combat Systems," Web site, September 19, 2005, at *www.army.mil/fcs/index.html* (October 17, 2007).
23. Mark O. Piggott, "USS Scranton Completes Successful UUV Test," *Navy Newsstand*, March 9, 2006, at *www.news.navy.mil/search/display.asp?story_id=22618* (June 26, 2006).
24. Edward C. Whitman, "Unmanned Underwater Vehicles: Beneath the Wave of the Future," *Undersea Warfare*, Vol. 4, Issue 3 (Summer 2002), at *www.navy.mil/navydata/cno/n87/usw/issue_15/wave.html* (June 26, 2006).

Continuing Development

Congress and the Administration should continue to promote the development of robotics. While the private sector is actively researching the application of robotics to a wide range of uses from building cars to sweeping floors, commercial research is not sufficiently focused on national security needs to develop the cutting-edge robotic applications that the military needs. Thus, in the decade ahead, commercial off-the-shelf products are unlikely to provide the Pentagon with dramatic new capabilities. Congress should therefore encourage and support national security robotic research.

Specifically, a few key initiatives would bolster the development and utilization of robots.

- **Interagency coordination.** Currently, each military service prefers separately managed programs geared to its individual needs. However, the Government Accountability Office (GAO) concluded that the military could save money and resources by combining the services' 13 UAV programs. The GAO cited the Fire Scout UAV program as an example of the potential of interagency cooperation. The Army and Navy are pursuing common components under the Navy contract, saving an estimated $200 million in research and development costs.[27]

  The Department of Defense should accelerate this type of cooperation, promoting common configurations, harmonizing performance requirements, and drawing on common testing, evaluation, and support. Cooperation should extend to the Department of Homeland Security, supporting the UAV requirements of the Coast Guard and Customs and Border Protection.
- **Continued funding.** Congress should continue to fund robotic research, development, and procurement across the board. Their success on the battlefield merits the resources necessary to meet the Pentagon's goal of replacing one-third of its armed vehicles and weaponry with robots by 2015.[28]
- **Establishing a legislative framework.** As autonomous robots come closer to becoming reality, safety will be a major issue. Robots, especially on the battlefield, should have "safety-critical computing" to maintain human control and to ensure they do not behave in unintended or dangerous ways.

  Public policy needs to recognize these dangers but to address them in a manner that does not unduly hold back research that could bring dramatic new capabilities to the marketplace and further national security. Congress can speed the development of autonomous robotics by creating a legal framework in which research can occur without unnecessary restraint. The framework should include input from the Defense Department, the Department of Homeland Security, and NASA.

A Window of Advantage

America's capability to seize and maintain a strategic advantage in robotic national security applications could be lost without sustained and focused commitment from the Administration and Congress. Congress should provide adequate funding, encourage increased coordination, and craft policies that encourage prudent investment in robotic technology. Congress can facilitate national security research and development programs by establishing a framework that addresses concerns about the risk to humans from autonomous robots.

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25. News release, "Two Boeing X-45As Complete Graduation Combat Demonstration," Boeing, August 10, 2005, at *www.boeing.com/news/releases/2005/q3/nr_050810m.html* (December 17, 2007).
26. Thomas P. Erhard and Robert O. Work, "The Unmanned Combat Air System Carrier Demonstration Program: A New Dawn for Naval Aviation," Center for Strategic and Budgetary Assessments *Backgrounder*, May 10, 2007, at *www.csbaonline.org/4Publications/PubLibrary/B.20070510.The_Unmanned_Comba/B.20070510.The_Unmanned_Comba.pdf* (December 5, 2007).
27. "Collaboration Key to ISR Programs," *C4ISR*, June 1, 2007.
28. "Robot Wars," *The Economist*, April 17, 2007, at *www.economist.com/science/tq/displaystory.cfm?story_id=9028041* (August 18, 2007).