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Military Robots and the Laws of War

P.W. Singer

More than just conventional wisdom, it has become almost a cliché to say that the wars in Afghanistan and Iraq have proved "how technology doesn't have a big place in any doctrine of future war," as one security analyst told me in 2007. The American military efforts in those countries (or so the thinking goes) have dispelled the understanding of technology-dominated warfare that was prevalent just a few years ago—the notion that modern armed conflict would be fundamentally changed in the age of computers and networks.

It is true that Afghanistan and Iraq have done much to puncture that understanding of war. The vaunted theory, so beloved in the Rumsfeld-era Pentagon, of a "network-centric" revolution in military affairs can now be seen more clearly as a byproduct of the 1990s dotcom boom. The Internet has certainly affected how people shop, communicate, and date. Amid this ecstatic hype, it is not surprising that many security studies experts, both in and out of the defense establishment, latched onto the notion that linking up all our systems via electronic networks would "lift the fog of war," allow war to be done on the cheap, and even allow the United States to "lock out" competition from the marketplace of war, much as they saw Microsoft doing to Apple at the time.

Nor is it surprising that now analysts are writing off high-tech warfare altogether in the wake of Afghanistan and Iraq. Insurgents armed with crude conventional weapons have proven frequently able to flummox their well-equipped American foes. Many observers increasingly seem to believe that if irregular warfare is likely to be the future of armed conflict, advanced technologies have no great role.

These "all or nothing" attitudes are each incorrect. High technology is not a silver bullet solution to insurgencies, but that doesn't mean that technology doesn't matter in these fights. In fact, far from proving the uselessness of advanced technology in modern warfare, Afghanistan and Iraq have for the first time proved the value of a technology that will truly revolutionize warfare—robotics.

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When U.S. forces went into Iraq, the original invasion had no robotic systems on the ground. By the end of 2004, there were 150 robots on the ground in Iraq; a year later there were 2,400; by the end of 2008, there were about 12,000 robots of nearly two dozen varieties operating on the ground in Iraq. As one retired Army officer put it, the "Army of the Grand Robotic" is taking shape.

It isn't just on the ground: military robots have been taking to the skies—and the seas and space, too. And the field is rapidly advancing. The robotic systems now rolling out in prototype stage are far more capable, intelligent, and autonomous than ones already in service in Iraq and Afghanistan. But even *they* are just the start. As one robotics executive put it at a demonstration of new military prototypes a couple of years ago, "The robots you are seeing here today I like to think of as the Model T. These are not what you are going to see when they are actually deployed in the field. We are seeing the very first stages of this technology." And just as the Model T exploded on the scene—selling only 239 cars in its first year and over one million a decade later—the demand for robotic warriors is growing very rapidly.

The truly revolutionary part, however, is not robots' increasing numbers, or even their capabilities. It is the ripple effects that they will have in areas ranging from politics and war to business and ethics. For instance, the difficulties for the existing laws of war that this robotics revolution will provoke are barely beginning to be understood. Technology generally evolves much more quickly than the laws of war. During World War I, for example, all sorts of recent inventions, from airplanes dropping bombs to cannons shooting chemical weapons, were introduced before anyone agreed on the rules for their use—and, as to be expected, the warring sides sometimes took different interpretations on critical questions. While it is far too early to know with any certainty, we can at least start to establish the underlying frameworks as to how robots will reshape the practice and the ethics of warfare.

Rise of the Robots

Mechanization and mass production made possible early automatic weapons in the nineteenth century. Military experimentation with machines that were also mobile and unmanned began during World War I—including even radio-controlled airplanes, the very first unmanned aerial vehicles (UAVs). World War II saw the operational use of several unmanned weapons by both the Allied and Axis forces, including remote-controlled bombs; it was also a period of rapid advancement in analog and electronic computing.

Military interest in robotics was spotty during the Cold War, with inventors repeatedly finding that what was technically possible mattered less than what was bureaucratically feasible. Robotic systems were getting better, but the interest, energy, and proven success stories necessary for them to take off just weren't there. The only substantial contract during this long dry spell was one that the Ryan aeronautical firm received in 1962 for $1.1 million to make an unmanned reconnaissance aircraft. The drone that came out of it, the Fire Fly, flew 3,435 missions in Southeast Asia. Overall, though, the Vietnam experience was as bad for robotics as it was for the broader U.S. military. Most of the uses of unmanned systems were classified and thus there was little public knowledge of their relative successes, as well as no field tests or data collection to solve the problems they incurred (16 percent of the Fire Flys crashed). As veteran robotics scientist Robert Finkelstein has pointed out, "It took decades for UAVs to recover from Vietnam misperceptions."

The next big U.S. military spending on unmanned planes didn't come until 1979, with the Army's Aquila program. The Aquila was to be a small propeller-powered drone that could circle over the front lines and send back information on the enemy's numbers and intentions. Soon, though, the Army began to load up the plane with all sorts of new requirements. It now had to carry night vision and laser designators, spot artillery fire, survive against enemy ground fire, and so on. Each new requirement came at a cost. The more you loaded up the drone, the bigger it had to be, meaning it was both heavier than planned and an easier target to shoot down. The more secure you wanted the communications, the lower the quality of the images it beamed back. The program originally planned to spend $560 million for 780 Aquila drones. By 1987, it had spent over $1 billion for just a few prototypes. The program was canceled and the cause of unmanned vehicles was set further back, again more by policy decisions than the technology itself.

Work continued, but mainly on testing various drones and ground vehicles, which were usually regular vehicles jury-rigged with remote controls. During this period, most of the ground systems were designed to be tele-operated—that is, using long fiber-optic wires to link the robot to the controller. Any enemy with a pair of scissors could take them out. One of the few to be built from the ground up to drive on its own was Martin Marietta's eight-wheeled "Autonomous Land Vehicle." Unfortunately, the weapon had a major image problem: It was shaped like an RV, what retirees would use to drive cross-country to see the Grand Canyon. This killed any chance of convincing the generals of its use for warfighting.

Another significant program that didn't take off in this period was a 1980 Army plan for a robotic antitank vehicle. The idea was to take a commercial all-terrain vehicle, rig it for remote control, and load it with missiles. Congress thought that ATVs, while certainly fun for country kids to ride around behind trailer parks, were a bit too small to be taking on Soviet tanks. So the program was canceled. But the military mistakenly came to believe that Congress's real objection was to the weaponization of unmanned systems. "So," as Finkelstein says, "misinterpretation kept weapons off for almost a decade."

Despite these setbacks, the American military robotics community didn't waver in its belief in the usefulness of its work. It could point to other nations beginning to successfully deploy unmanned systems, like Israel's successful experience with drones in the 1980s. By the time of the 1991 Persian Gulf War, unmanned systems were gradually making their way into the U.S. military, but in very small numbers. The Army had a handful of M-60 tanks converted into unmanned land-mine clearers, but they were left behind in the famous "left-hook" invasion force that drove across the desert into Iraq. The Air Force flew just one UAV drone. The only notable success story was the Navy's use of the Pioneer drone, an unmanned plane (almost exactly like the planned Aquila) that the Navy had bought secondhand from the Israelis. It flew off of World War II-era U.S. battleships that had been taken out of mothballs in the 1980s and updated for use in pounding ground targets with their massive sixteen-inch guns. The guns fired shells that weighed 2,000 pounds and could leave a crater the size of a football field. The little drones, which the Iraqis took to calling "vultures," would fly over targets and spot where the shells were landing. "The Iraqis came to learn that when they heard the buzz of a Pioneer overhead, all heck would break loose shortly thereafter because these sixteen-inch rounds would start landing all around them," said Steve Reid, an executive at the Pioneer's maker, AAI. In one case, a group of Iraqi soldiers saw a Pioneer flying overhead and, rather than wait to be blown up, waved white bed sheets and undershirts at the drone—the first time in history that human soldiers surrendered to an unmanned system.

Of course, the real stars of the Gulf War were not unmanned systems in the way we think of them now, but new "smart bombs"—that is, cruise missiles and laser-guided bombs. A massive PR campaign was built around the guided weapons as the "heroes" of the hundred-hour war. The only problem was that they weren't. Only 7 percent of all the bombs dropped were guided; the rest were "dumb." The most influential technology in the Gulf War was not the sexy smart bombs, but the humble desktop computer. By 1990, the U.S. military had bought into the idea of digitizing its forces and was spending some $30 billion a year on applying computers to all its various tasks. The Gulf War was the first war in history to involve widespread computers, used for everything from organizing the movement of hundreds of thousands of troops to sorting through reams of satellite photos looking for targets for missiles to hit. Calling it a "technology war," the victorious commanding general, "Stormin'" Norman Schwarzkopf, said, "I couldn't have done it all without the computers."

Over the rest of the 1990s, as sensors and computer processors improved, unmanned systems became ever more capable. But the "magic moment," as retired Air Force Colonel Tom Erhard put it, occurred in 1995, when unmanned systems were integrated with the Global Positioning System (GPS). "That's when it really came together." Now widely accessible by devices in automobiles, the GPS is a constellation of military satellites that can provide the location, speed, and direction of a receiver, anywhere on the globe. It allowed unmanned systems (and their human operators) to automatically know where they were at any time. With GPS, as well as the advance of the video game industry (which the controllers began to mimic), the interfaces became accessible to a wider set of users. Drones began to be far more intuitive to fly, while the information they passed on to the generals and troops in the field became ever more detailed.

The programs also began to pass some key hurdles of acceptability. The various military services had long resisted buying any unmanned systems, but slowly they began to accept their use. In 1997, for example, the Air Force Chief of Staff, General Ronald R. Fogleman, instructed his planners that his service could "no longer…spend money the way we have been," and mandated that they consider investing in new technologies such as UAVs. The military advantages of unmanned systems became increasingly clear to observers in the Pentagon. In many situations, robots have faster reaction times and better aim than human beings. They are often ideal for filling roles that people in the field call the "Three Ds": dull, dirty, or dangerous. Unlike humans, who get tired and hungry and lose concentration and effectiveness, robots can perform boring tasks with unstinting accuracy for long periods of time. (As one advertisement for an unmanned plane put it, "Can you keep your eyes open for thirty hours without blinking?") They can operate in dirty environments, such as battle zones filled with biological or chemical weapons, or under other dangerous conditions, such as in space, in rough seas, or in flights with very high gravitational pressures.

The rising interest in robots in the late 1990s coincided with changing political winds—a shrinking U.S. military as part of the post-Cold War so-called "peace dividend," and an increasing belief that public tolerance for military risk and casualties had dropped dramatically after the relatively costless victory in the Gulf War. In 2000, this was the main factor that led Senator John Warner (R.-Va.), then chairman of the Armed Services Committee, to mandate in the Pentagon's budget that by 2010, one-third of all the aircraft designed to attack behind enemy lines be unmanned, and that by 2015, one-third of all ground combat vehicles be driverless.

And then came September 11, 2001. The annual national defense budget since 9/11 has risen to $515 billion (an increase of 74 percent between 2002 and 2008), not counting the cost of operations in Afghanistan and Iraq. There has been a massive increase in spending on research and development and on procurement, with a particular focus on anything unmanned. "Make 'em as fast as you can" is what one robotics executive recounts being told by his Pentagon buyers after 9/11. Enthusiasm has only grown thanks to successes on the battlefield.

With this change in military mentality, money, and use, the groundwork was finally laid for a real military robotics industry. As the *Washington Post* put it, "The undertaking has attracted not only the country's top weapons makers but also dozens of small businesses…all pitching a science-fiction gallery of possible solutions." Robert Finkelstein recalled a time when he personally knew most of the engineers working on military robotics. Today, the Association for Unmanned Vehicle Systems International has fourteen hundred member companies. Almost four thousand people showed up at its last annual meeting.

Cleaning Floors and Fighting Wars

During the war in Iraq, improvised explosive devices (IEDs) became the insurgents' primary way of attacking U.S. forces. Often hidden along roadsides and disguised to look like trash or scrap metal, these cheap and easy-to-make bombs can do tremendous damage. At the peak of the Iraq insurgency in 2006, IED attacks were averaging nearly two thousand a month. They have been the leading cause of casualties among American personnel in Iraq, accounting for 40 percent of the troop deaths.

On the ground, the military bomb squad hunting for IEDs is called the Explosive Ordnance Disposal (EOD) team. Before Iraq, EOD teams were not much valued by either the troops in the field or their senior leaders. They usually deployed to battlefields only after the fighting was done, to defuse any old weapons caches or unexploded ammunition that might be found. In Iraq, though, EOD teams went from an afterthought to a critical assignment. In a typical tour in Iraq when the insurgency was at its peak, each team would go on more than six hundred IED calls, defusing or safely exploding about two IEDs a day. Perhaps the best sign of how critical the EOD teams became is that the insurgents began offering a rumored $50,000 bounty for killing an EOD team member.

Working alongside many EOD teams have been robots—scouting ahead for IEDs and ambushes, saving soldiers' lives many times over. Most of these unmanned ground vehicles (UGVs) have been made by two Boston-area robotics firms. One of these, iRobot, was founded in 1990 by three M.I.T. computer geeks; it is best known for the Roomba, the disc-shaped automatic vacuum cleaner that the company released in 2002. Roomba actually evolved from Fetch, a robot that the company designed in 1997 for the U.S. Air Force. Fetch cleaned up cluster bomblets from airfields; Roomba cleans up dust bunnies under sofas.

The company's other breakout product was PackBot, which came out of a 1998 contract from the Defense Advanced Research Projects Agency (DARPA). Weighing forty-two pounds and costing just under $150,000, PackBot is about the size of a lawn mower. It is typically operated via remote control, although it can drive itself, including even backtracking to wherever it started its mission. PackBot moves using four "flippers"—essentially tank treads that can rotate on one axis. These allow PackBot not only to roll forward and backward like regular tank tracks, but also to climb stairs, rumble over rocks, squeeze down twisting tunnels, and even swim in under six feet of water.

The designers at iRobot view their robots as "platforms." PackBot has eight separate payload bays and hookups that allow its users to swap in whatever they need: mine detector, chemical and biological weapons sensor, or just extra power packs. The EOD version of the PackBots serving in Iraq comes with an extendable arm on top that mounts both a head, containing a high-powered zoom camera, and a claw-like gripper. Soldiers use these to drive up to IEDs, peer at them closely, and then, using the gripper, disassemble the bomb, all from a safe distance.

PackBot made its operational debut on 9/11 when engineers from iRobot drove down to New York City to help in the rescue and recovery efforts at Ground Zero. Soon after, PackBot went to war. As U.S. forces deployed to Afghanistan, troops came across massive cave complexes that had to be scouted out, but were often booby-trapped. The only specialized tool the troops had were flashlights, and they often sent their local Afghan allies to crawl through the caves on hands and knees. "Then we began to run out of Afghans," recounts a soldier. iRobot was then asked by the Pentagon to send help. Just six weeks later, PackBots were first used in a cave complex near the village of Nazaraht, in the heart of Taliban territory. Production and profits for Packbots boomed in the years that followed, culminating in a $286 million Pentagon contract in 2008 to supply as many as three thousand more machines.

Meanwhile, iRobot has new and improved versions of the PackBot as well as a host of plans to convert any type of vehicle into a robot, be it a car or ship, using a universal control unit that you plug into the engine and steering wheel. One new robot that iRobot's designers are especially excited to show off is the Warrior. Weighing about 250 pounds, the Warrior is essentially a PackBot on steroids: it has the same basic design, but is about five times bigger. Warrior can drive at 15 miles per hour for five hours, while carrying one hundred pounds—yet it is agile enough to fit through a doorway and go up stairs. It is really just a mobile platform, with a USB port—a universal connector—on top that can be used to plug in sensors, a gun, and a TV camera for battle, or an iPod and loudspeakers for a mobile rave party. The long-term strategy is for other companies to focus on the plug-in market while iRobot corners the market for the robotic platforms. What Microsoft did for the software industry, iRobot hopes to do for the robotics industry.

Just a twenty-minute drive from iRobot's offices are the headquarters of the Foster-Miller company. Founded in the 1950s—also by M.I.T. grads—Foster-Miller makes the PackBot's primary competitor, the Talon. The Talon, which first hit the market in 2000, looks like a small tank, driven by two treads that run its length. Weighing just over a hundred pounds, it is a bit bigger than the PackBot. It too has a retractable arm with a gripper, but mounts its main sensors on a separate antenna-like "mast" sticking up from the body and carrying a zoom camera. Talon can go up to speeds of about 5.5 miles per hour, the equivalent of a decent jog on a treadmill, a pace it can maintain for five hours.

Like the PackBot, the Talon helped sift through the wreckage at Ground Zero and soon after deployed to Afghanistan. And like iRobot, Foster-Miller has boomed, doubling the number of robots it sells every year for the last four years. The company received an initial $65 million in orders for Talons in the first two years of the insurgency in Iraq. By 2008, there were close to two thousand Talons in the field and the firm had won a $400 million contract to supply another two thousand. Under an additional $20 million repair and spare-parts contract, the company also operates a "robot hospital" in Baghdad. Foster-Miller now makes some fifty to sixty Talons a month, and repairs another hundred damaged systems.

In technology circles, new products that change the rules of the game, such as what the iPod did to portable music players, are called "killer applications." Foster-Miller's new product gives this phrase a literal meaning. The Special Weapons Observation Reconnaissance Detection System (SWORDS) is the first armed robot designed to roam the battlefield. SWORDS is basically the Talon's tougher big brother, with its gripping arm replaced by a gun mount that can carry pretty much any weapon that weighs under three hundred pounds, ranging from an M-16 rifle and .50-caliber machine gun to a 40mm grenade launcher or an anti-tank rocket launcher. In less than a minute, the human soldier flips two levers and locks his favorite weapon into the mount. The SWORDS can't reload itself, but it can carry two hundred rounds of ammunition for the light machine guns, three hundred rounds for the heavy machine guns, six grenades, or four rockets.

Unlike the more-automated PackBot, SWORDS has very limited intelligence on its own; it is remote-controlled from afar by either radio or a spooled-out fiber optic wire. Thanks to the five cameras mounted on the robot, the operator can not only see as if he has eyes in the back of his head, but farther than had previously been possible when shooting a gun. As one soldier put it, "You can read people's nametags at 300 to 400 meters, whereas the human eye can't pick that up. You can see the expression on his face, what weapons he is carrying. You can even see if his [weapon's] selector lever is on fire or on safe." The cameras can also see in night vision, meaning the enemy can be fired on at any hour and in any climate. And the gun is impressively precise; it is locked in a stable platform, so its aim isn't disrupted by the breathing or heartbeat that human snipers must compensate for, and it doesn't get nervous in a sticky situation.

So far, SWORDS has been used for street patrols, reconnaissance, sniping, checkpoint security, and guarding observation posts. It bodes to be especially useful for urban warfare jobs, such as going first into buildings and alleyways where insurgents might hide. SWORDS's inhuman capabilities could well result in even more intrepid missions. For example, the robot can drive through snow and sand, and can even drive underwater down to depths of one hundred feet, meaning it could pop up in quite unexpected places. Likewise, its battery allows it to be hidden somewhere in "sleep" mode for at least seven days and then wake up to shoot away at any foes.

Foster-Miller and iRobot feel a keen sense of competition with each other. At iRobot, researchers describe their rivals as thinking, "We hear that robots are trendy, so let's do that." At Foster-Miller, they retort, "We don't just do robots and we don't suck dirt." (Indeed, thanks to its Roomba vacuum cleaner, iRobot may be the only company that sells at both Pentagon trade shows and Bed Bath & Beyond.) The two companies have even become locked in a bit of a marketing war. If robots were pickup trucks, Foster-Miller represents the Ford model, stressing how the Talon is "Built Tough." Its promotional materials describe the Talon as "The Soldier's Choice." Foster-Miller executives love to recount tales of how the Talon has proven it "can take a punch and stay in the fight." The iRobot team, meanwhile, bristles at the idea that its systems are "agile but fragile." They insist that the PackBot is tough, too, citing various statistics on how it can survive a 400 g-force hit, what they describe as the equivalent of being tossed out of a hovering helicopter onto a concrete floor. They are most proud of the fact that their robots have a 95 percent out-of-the-box reliability rate, higher than any other in the marketplace, meaning that when the soldiers get them in the field, they can trust the robot will work as designed.

Beneath all the difference and rancor, the two companies are similar in one telling way. The hallways and cubicles of both of their offices are covered with pictures and thank-you letters from soldiers in the field. A typical note from an EOD soldier reads, "This little guy saved our butts on many occasions."

Future Ground-Bots

Foster-Miller's SWORDS was not the first ground robot to draw blood on the battlefield. That seems to have been the MARCBOT (Multi-Function Agile Remote-Controlled Robot), a commonly-used UGV that looks like a toy truck with a video camera mounted on a tiny antenna-like mast. Costing only $5,000, the tiny bot is used to scout out where the enemy might be and also to drive under cars and search for hidden explosives. One unit of soldiers put Claymore antipersonnel mines on their MARCBOTs. Whenever they thought insurgents were hiding in an alley, they would send a MARCBOT down first, not just to scout out the ambush, but to take them out with the Claymore. Of course, each discovered insurgent meant $5,000 worth of blown-up robot parts, but so far the Army hasn't billed the soldiers.

Meanwhile, both iRobot and Foster-Miller are hard at work on the next generation of UGVs. For testing purposes, iRobot's PackBot has been equipped with a shotgun that can fire a variety of ammunition, including non-lethal rubber bullets, rounds that can blow down a door, and even more powerful "elephant killer" bullets. Another version of PackBot is the Robotic Enhanced Detection Outpost with Lasers (REDOWL), which uses lasers and sound detection equipment to find any sniper who dares to shoot at the robot or accompanying troops, and instantly targets him with an infrared laser beam.

Foster-Miller has similar plans to upgrade its current generation of ground robots. For example, the first version of the armed SWORDS needed the remote human operator to be situated within a mile or two, which can still put the human in danger. The company plans to vastly extend the range of communications so as to get ground robot operators completely off the battlefield. And the SWORDS itself is being replaced by a new version named after the Roman god of war—the MAARS (Modular Advanced Armed Robotic System), which carries a more powerful machine gun, 40mm grenade launchers, and, for non-lethal settings, a green laser "dazzler," tear gas, and a loudspeaker, perfect for warning any insurgents that "Resistance is futile."

We will also soon see entirely new armed UGVs hit the battlefield. One such prototype is the Gladiator. Described as the "world's first multipurpose combat robot," it came out of a partnership between the U.S. Marine Corps and Carnegie Mellon University. About the size of a golf cart, the first version of the vehicle was operated by a soldier wielding a PlayStation video game controller, but software plug-ins will allow it to be upgraded to semiautonomous and then fully autonomous modes. Fully loaded, it costs $400,000 and carries a machine gun with six hundred rounds of ammunition, antitank rockets, and non-lethal weapons.

Not all future UGVs, it should be noted, will take on combat roles. Some are being designed as "medbots," to supplement the work of field medics. The Bloodhound, yet another version of the PackBot, will be able to search on its own for a hurt soldier; it can then be remotely controlled to provide rudimentary treatment. The next step will be specially designed medbots, such as REV and REX. REV, the Robotic Evacuation Vehicle (a robot version of an ambulance), carries REX, the Robotic Extraction Vehicle, a tiny stretcher-bearer that zips out to drag soldiers into the safety of the ambulance. REX has an arm with six joints to drag a soldier to safety, while REV has a life-support pod that even comes with a flat-screen TV facing the wounded soldier's face so that operators can see and communicate with the human on the other end if he is conscious. Ultimately, REV will be configured so that complex surgeries can occur inside the medbot.

Coordinating many of the ground robots on the drawing boards is the U.S. Army's $230 billion Future Combat Systems (FCS) program. It involves everything from replacing tens of thousands of armored vehicles with a new generation of manned and unmanned vehicles to writing the many millions of lines of software code for the new computers that will link them all together. Starting in 2011, the Army plans to start spiraling a few new technologies at a time into the force. By 2015, the Army believes it will be in a position to reorganize its units into new FCS brigades, which will represent a revolutionary new model of how military units are staffed and organized. Each brigade will actually have more unmanned vehicles than manned ones (a planned 330 unmanned to 300 manned). Each brigade will also have its own unmanned air force, with over a hundred drones controlled by the unit's soldiers. They will range in size from a fifteen-pounder that will fit in soldiers' backpacks to a twenty-three-foot-long robotic helicopter.

Up, Up, and Away

Military robots have also taken to the skies. Unmanned aerial vehicles (UAVs), like the now-well-known Predator and Global Hawk, made their debut in the Balkan wars in the 1990s, gathering information on Serb air defenses and refugee flows. These drones are an indispensable part of the U.S. efforts in Afghanistan and Iraq, but commanders' attitudes toward them were very different just a few years ago. Lieutenant General Walter Buchanan, the U.S. Air Force commander in the Middle East, recalled the run-up to the Iraq war in an interview with *Air Force Magazine*:

> In March of 2002, [during] the mission briefings over Southern Iraq at that time, the mission commander would get up and he'd say, "OK, we're going to have the F-15Cs fly here, the F-16s are going to fly here, the A-6s are going to fly here, tankers are going to be here today." Then they would say, "And oh by the way, way over here is going to be the Predator." We don't go over there, and he's not going to come over here and bother us.... It was almost like nobody wanted to talk to them.

This is far from the case today. The Predator, perhaps the best known UAV, is a twenty-seven-foot-long plane that can spend some twenty-four hours in the air, flying at heights of up to 26,000 feet. Given its price tag—at just $4.5 million, it costs a fraction of what a manned fighter jet costs—the Predator can be used for missions where it might be shot down, such as traveling low and slow over enemy territory. It was originally designed for reconnaissance and surveillance, and about a quarter of the cost of each Predator actually goes into the "Ball," a round mounting under the nose that carries two variable-aperture TV cameras, one for seeing during the day and an infrared one for night, as well as a synthetic-aperture radar that allows the Predator to peer through clouds, smoke, or dust. The exact capabilities of the system are classified, but soldiers say they can read a license plate from two miles up.

Predators don't just watch from afar; they have also been armed to kill. The back-story of how this happened is one of the sad "what ifs?" of what could have been done to prevent the 9/11 attacks. Over the course of 2000 and 2001, Predators operated by the CIA spotted Osama bin Laden in Afghanistan many times, usually when he was driving in a convoy between his training camps. But the unmanned spy planes were toothless and could only watch as bin Laden disappeared. Proposals to arm the drone by mounting laser-guided Hellfire missiles on its wings were not pursued.

After 9/11, the gloves were taken off, and the CIA and Air Force armed their Predators. In the first year, armed Predators took out some 115 targets in Afghanistan on their own. (That's in addition to the thousands of targets that were destroyed by other means after they were laser-designated by Predators.) With that precedent, the Predator also joined the fight in Iraq. Among its first missions was to help take down the Iraqi government's television transmissions, which broadcast the infamous "Baghdad Bob" propaganda. In the days and weeks that followed, the Predator struck at everything from suspected insurgent safe houses to cars being prepped for suicide attacks. The little drone has quickly become perhaps the busiest U.S. asset in the air. From June 2005 to June 2006, Predators carried out 2,073 missions, flew 33,833 hours, surveyed 18,490 targets, and participated in 242 separate raids. Even with this massive effort, there is demand for more. Officers estimate that they get requests for some 300 hours of Predator imagery a day, but that there are only enough Predators in the air to supply a little over 100 hours a day. The result is that the Predator fleet has grown from less than 10 in 2001 to some 180 in 2007, with plans to add another 150 over the next few years.

Besides the Predator, there are many other drones that fill the air over Iraq and Afghanistan. At forty feet long, Global Hawk has been described as looking like "a flying albino whale." Originally conceived as an unmanned replacement for the half-century-old U-2 spy plane, Global Hawk can stay aloft up to thirty-five hours. Powered by a turbofan engine that takes it to sixty-five thousand feet, the stealthy Global Hawk carries synthetic-aperture radar, infrared sensors, and electro-optical cameras. Working in combination, these sensors can do a wide-area search to look at an entire region, or focus in on a single target in high resolution. Like the Predator, the Global Hawk is linked back to humans on the ground, but it mainly operates autonomously rather than being remotely piloted. Using a computer mouse, the operator just clicks to tell it to taxi and take off, and the drone flies off on its own. The plane then carries out its mission, getting directions on where to fly from GPS coordinates downloaded off a satellite. Upon its return, "you basically hit the land button," describes one retired Air Force officer.

With such capability, the Global Hawk is not cheap. The plane itself costs some $35 million, but the overall support system runs to over $123 million each. Even so, the U.S. Air Force plans to spend another $6 billion to build up the fleet to fifty-one drones by 2012.

The Predators and Global Hawks are mostly directed by personnel in Air Force bases back in the United States, but a veritable menagerie of UAVs now circling above Iraq are controlled by troops on the ground. Big Army units fly the Shadow, which looks like the radio-controlled planes flown by model plane hobbyists. Just over twelve feet long, it takes off and lands like a regular plane, and its propeller makes it sound like a weed-whacker flying overhead; it can stay in the air for five hours and fly seventy miles. Like its older sibling the Hunter, which is twice as big and can stay in the air twice as long, the Shadow is used on a variety of tactical missions in support of ground forces, including reconnaissance, target acquisition, and battlefield damage assessment.

The Raven, the most popular UAV, is just thirty-eight inches long and weighs four pounds; it is launched by tossing it into the air like a javelin. The Raven then buzzes off, able to fly for ninety minutes at about four hundred feet, carrying three cameras in its nose, including an infrared one. Soldiers love it because they can now peer over the next hill or city block, as well as get their own spy planes to control, rather than having to beg for support from the higher-ups. "You throw the bird up when you want to throw it. You land it when you want to land," says Captain Matt Gill, a UAV company commander with the 82nd Airborne Division. The other part of the appeal is that the pilots of the Raven are just regular soldiers; one cook from the 1st Cavalry Division is actually considered among the best pilots in the entire force. In just the first two years of the Iraq war, the number of Ravens in service jumped from twenty-five to eight hundred.

The small UAVs, like the Raven or the even smaller Wasp, fly just above the rooftops, sending back video images of what's on the other side of the street; Shadow and Hunter circle over entire neighborhoods; the larger Predators roam above entire cities, combining reconnaissance with the ability to shoot; and too high to see, the Global Hawk zooms across an entire country, capturing reams of detailed imagery for intelligence teams to sift through. Added together, by 2008, there were 5,331 drones in the U.S. military's inventory, almost double the number of manned fighter planes. That same year, an Air Force lieutenant general forecast that "given the growth trends, it is not unreasonable to postulate future conflicts involving tens of thousands."

Among the UAVs likely to see action in those future conflicts will be Predators reconfigured for electronic warfare, submarine hunting, and even air-to-air combat; the Reaper, a bigger, smarter, and more powerful successor to the Predator; a variety of planned micro-UAVs, some the size of insects; the Peregrine, a drone designed to find and shoot down other drones; and even an unmanned stealth bomber. And it's not just intelligence and bomber pilots who will be replaced with machines; planning is proceeding on UCAVs, unmanned *combat* aerial vehicles, which will replace fighter jocks, too.

Meanwhile, DARPA is working on a VULTURE (Very-high-altitude, Ultra-endurance, Loitering Theater Unmanned Reconnaissance Element) drone, which the agency hopes will be able to stay aloft for as long as five years. We may even see the return of blimps to warfare. Lockheed Martin has been given $150 million to design and build a robotic "High Altitude Airship" twenty-five times larger than the Goodyear blimp. Such huge, long-endurance blimps open up a whole new range of roles not normally possible for planes. For example, airships could literally be "parked" in the air, as high as one hundred thousand feet up, for weeks, months, or years, serving as a communications relay, spy satellite, hub for a ballistic missile defense system, floating gas station, or even airstrip for other planes and drones.

The Pentagon has also started work on a number of unmanned systems for potential use in space, although most are still only on the drawing boards. And a broad new set of robots is being introduced for war at sea, too, where the main differentiation is whether they are designed to operate on the surface, like a boat, or underwater, like a submarine. The former are called USVs (unmanned surface vehicles or vessels). They actually have a great deal in common with the simpler land robots, as they both primarily operate in a two-dimensional world, and can be equipped with sensors and guns. The Spartan Scout, one such USV, got its first real-world use in the Iraq war in 2003, inspecting small civilian boats in the Persian Gulf without risking sailors' lives. The boat also mounts a loudspeaker and microphone, so an Arab linguist back on the "mothership" could interrogate any suspicious boats that the Spartan Scout had stopped. As one report put it, "The civilian sailors were somewhat taken aback when they were interrogated by this Arab-speaking boat that had no one aboard."

The other type of navybots are UUVs (unmanned underwater vehicles). These are designed for underwater roles such as searching for mines, the cause of most naval combat losses over the last two decades. Many UUVs are biologically inspired, like the "Robo-lobster," which operates in the choppy waters close to shore. But others are mini-submarines or converted torpedoes—like the REMUS (Remote Environmental Monitoring Unit), which was used to clear Iraqi waterways of mines and explosives.

Impersonalizing War

The hope that technology will reduce the violence of war is a venerable one. The poet John Donne told in 1621 how the invention of better cannons would help limit the cruelty and crimes of war, "and the great expence of bloud is avoyed." Richard Gatling hoped his new fast-firing gun would serve to reduce the bloodshed of war, while Alfred Nobel believed the explosives he invented would make war unthinkable. Now, some analysts believe that robot warriors can help reduce the flow of blood and perhaps make war more moral.

In some ways, this seems reasonable. Many wartime atrocities are not the result of deliberate policy, wanton cruelty, or fits of anger; they're just mistakes. They are equivalent to the crime of manslaughter, as compared to murder, in civilian law. Unmanned systems seem to offer several ways of reducing the mistakes and unintended costs of war. They have far better sensors and processing power, which creates a precision superior to what humans could marshal on their own. Such exactness can lessen the number of mistakes made, as well as the number of civilians inadvertently killed. For example, even as recently as the 1999 Kosovo war, NATO pilots spotting for Serbian military targets on the ground had to fly over the suspected enemy position, then put their plane on autopilot while they wrote down the coordinates of the target on their lap with a grease pencil. They would then radio the coordinates back to base, where planners would try to figure out if there were too many civilians nearby. If not, the base would order an attack, usually made by another plane. That new plane, just arriving on the scene, would carry out the attack using the directions of the spotter plane, if it was still there, or the relayed coordinates. Each step was filled with potential for miscommunications and unintended errors. Plus, by the time a decision had been made, the situation on the ground might have changed—the military target might have moved or civilians might have entered the area.

Compare this with a UAV today that can fly over the target and send precise GPS coordinates and live video back to the operators; it is easy to see how collateral damage can be greatly reduced by robotic precision.

The unmanning of the operation also means that the robot can take risks that a human wouldn't otherwise, risks that might mean fewer mistakes. During that Kosovo campaign, for example, such a premium was placed on not losing any NATO pilots that planes were restricted from flying below fifteen thousand feet so that enemy fire couldn't hit them. In one case, NATO planes flying at this level bombed a convoy of vehicles, thinking they were Serbian tanks. It turned out to be a convoy of refugee buses. If the planes could have flown lower or had the high-powered video camera of a drone, this tragic mistake might have been avoided.

The removal of risk also allows decisions to be made in a more deliberate manner than normally possible. Soldiers describe how one of the toughest aspects of fighting in cities is how you have to burst into a building and, in a matter of milliseconds, figure out who is an enemy and who is a civilian and shoot the ones that are a threat before they shoot you, all the while avoiding hitting any civilians. You can practice again and again, but you can never fully avoid the risk of making a terrible mistake in that split second, in a dark room, in the midst of battle. By contrast, a robot can enter the room and only shoot at someone who shoots first, without endangering a soldier's life.

Many also feel that unmanned systems can remove the anger and emotion from the humans behind them. A remote operator isn't in the midst of combat and isn't watching his buddies die around him as his adrenaline spikes; he can take his time and act deliberately in ways that can lessen the likelihood of civilians being killed. Marc Garlasco of Human Rights Watch told me how "the single most distinguishing weapons I have seen in my career were Israeli UAVs." He described how, unlike jet fighters that had to swoop in fast and make decisions on what targets to bomb in a matter of seconds, the UAVs he observed during the 2006 Lebanon war could loiter over a potential target for minutes or even hours, and pick and choose what to strike or not. In Vietnam, an astounding fifty thousand rounds of ammunition were expended for every enemy killed. Robots, on the other hand, might live up to the sniper motto of "one shot, one kill." As journalist Michael Fumento put it in describing SWORDS, the operator "can coolly pick out targets as if playing a video game."

But as journalist Chuck Klosterman put it, a person playing video games is usually "not a benevolent God." We do things in the virtual world, daring and violent things, that we would never do if we were there in person. Transferred to war, this could mean that the robotic technologies that make war less intimate and more mediated might well reduce the likelihood of anger-fueled rages, but also make some soldiers *too* calm, too unaffected by killing. Many studies, like Army psychologist Dave Grossman's seminal book *On Killing* (1995), have shown how disconnecting a person, especially via distance, makes killing easier and abuses and atrocities more likely. D. Keith Shurtleff, an Army chaplain and the ethics instructor for the Soldier Support Institute at Fort Jackson in South Carolina, worries that "as war becomes safer and easier, as soldiers are removed from the horrors of war and see the enemy not as humans but as blips on a screen, there is a very real danger of losing the deterrent that such horrors provide."

Participation via the virtual world also seems to affect not merely how people look at the target, but also how they look at themselves (which is why people in online communities, for example, take on identities and try out behaviors they never would in real life). Research shows that this sort of "externalization" allows something called "doubling." Otherwise nice and normal people create psychic doubles that carry out sometimes terrible acts their normal identity never would. One Air Force lieutenant colonel who led a Predator operation noticed how the virtual setting could make it easy for the drone operators to forget that they were not gods from afar and that there are real humans on both ends. "You have guys running the UAV saying, 'Kill that one, don't kill that one.'" Each new military technology, from the bow and arrow to the bomber plane, has moved soldiers farther and farther from their foes. Yet unmanned systems have a more profound effect on "the impersonalization of battle," as military historian John Keegan has called it. These weapons don't just create greater physical distance, but also a different sort of psychological distance and disconnection. The bomber pilot isn't just above his target, but seven thousand miles away. He doesn't share with his foes even those brief minutes of danger that would give them a bond of mutual risk.

We, Robot

As military robots gain more and more autonomy, the ethical questions involved will become even more complex. The U.S. military bends over backwards to figure out when it is appropriate to engage the enemy and how to limit civilian casualties. Autonomous robots could, in theory, follow the rules of engagement; they could be programmed with a list of criteria for determining appropriate targets and when shooting is permissible. The robot might be programmed to require human input if any civilians were detected. An example of such a list at work might go as follows: "Is the target a Soviet-made T-80 tank? Identification confirmed. Is the target located in an authorized free-fire zone? Location confirmed. Are there any friendly units within a 200-meter radius? No friendlies detected. Are there any civilians within a 200-meter radius? No civilians detected. Weapons release authorized. No human command authority required."

Such an "ethical" killing machine, though, may not prove so simple in the reality of war. Even if a robot has software that follows all the various rules of engagement, and even if it were somehow absolutely free of software bugs and hardware failures (a big assumption), the very question of figuring out who an enemy is in the first place—that is, whether a target should even be considered for the list of screening questions—is extremely complicated in modern war. It essentially is a judgment call. It becomes further complicated as the enemy adapts, changes his conduct, and even hides among civilians. If an enemy is hiding behind a child, is it okay to shoot or not? Or what if an enemy is plotting an attack but has not yet carried it out? Politicians, pundits, and lawyers can fill pages arguing these points. It is unreasonable to expect robots to find them any easier.

The legal questions related to autonomous systems are also extremely sticky. In 2002, for example, an Air National Guard pilot in an F-16 saw flashing lights underneath him while flying over Afghanistan at twenty-three thousand feet and thought he was under fire from insurgents. Without getting required permission from his commanders, he dropped a 500-pound bomb on the lights. They instead turned out to be troops from Canada on a night training mission. Four were killed and eight wounded. In the hearings that followed, the pilot blamed the ubiquitous "fog of war" for his mistake. It didn't matter and he was found guilty of dereliction of duty.

Change this scenario to an unmanned system and military lawyers aren't sure what to do. Asks a Navy officer, "If these same Canadian forces had been attacked by an autonomous UCAV, determining who is accountable proves difficult. Would accountability lie with the civilian software programmers who wrote the faulty target identification software, the UCAV squadron's Commanding Officer, or the Combatant Commander who authorized the operational use of the UCAV? Or are they collectively held responsible and accountable?"

This is the main reason why military lawyers are so concerned about robots being armed and autonomous. As long as "man is in the loop," traditional accountability can be ensured. Breaking this restriction opens up all sorts of new and seemingly irresolvable legal questions about accountability.

In time, the international community may well decide that armed, autonomous robots are simply too difficult, or even abhorrent, to deal with. Like chemical weapons, they could be banned in general, for no other reason than the world doesn't want them around. Yet for now, our laws are simply silent on whether autonomous robots can be armed with lethal weapons. Even more worrisome, the concept of keeping human beings in the loop is already being eroded by policymakers and by the technology itself, both of which are rapidly moving toward pushing humans out. We therefore must either enact a ban on such systems soon or start to develop some legal answers for how to deal with them.

If we do stay on this path and decide to make and use autonomous robots in war, the systems must still conform with the existing laws of war. These laws suggest a few principles that should guide the development of such systems.

First, since it will be very difficult to guarantee that autonomous robots can, as required by the laws of war, discriminate between civilian and military targets and avoid unnecessary suffering, they should be allowed the autonomous use only of non-lethal weapons. That is, while the very same robot might also carry lethal weapons, it should be programmed such that only a human can authorize their use.

Second, just as any human's right to self-defense is limited, so too should be a robot's. This sounds simple enough, but oddly the Pentagon has already pushed the legal interpretation that our drones have an inherent right to self-defense, including even to preemptively fire on potential threats, such as an anti-aircraft radar system that lights them up. There is a logic to this argument, but it leads down a very dark pathway; self-defense must not be permitted to trump other relevant ethical concerns.

Third, the human creators and operators of autonomous robots must be held accountable for the machines' actions. (Dr. Frankenstein shouldn't get a free pass for his monster's misdeeds.) If a programmer gets an entire village blown up by mistake, he should be criminally prosecuted, not get away scot-free or merely be punished with a monetary fine his employer's insurance company will end up paying. Similarly, if some future commander deploys an autonomous robot and it turns out that the commands or programs he authorized the robot to operate under somehow contributed to a violation of the laws of war, or if his robot were deployed into a situation where a reasonable person could guess that harm would occur, even unintentionally, then it is proper to hold the commander responsible.

To ensure that responsibility falls where it should, there should be clear ways to track the authority in the chain of design, manufacture, ownership, and use of unmanned systems, all the way from the designer and maker to the commanders in the field. This principle of responsibility is not simply intended for us to be able to figure out whom to punish after the fact; by establishing at the start who is ultimately responsible for getting things right, it might add a dose of deterrence into the system before things go wrong.

Not merely scientists, but everyone from theologians (who helped create the first laws of war) to the human rights and arms control communities must start looking at where this technological revolution is taking both our weapons and laws. These discussions and debates also need to be global, as the issues of robotics cross national lines (forty-three countries now have military robotics programs). Over time, some sort of consensus might emerge—if not banning the use of all autonomous robots with lethal weapons, then perhaps banning just certain types of robots (such as ones not made of metal, which would be hard to detect and thus of most benefit to terrorist groups).

Some critics will argue against any international discussions or against creating new laws that act to restrict what can be done in war and research. As Steven Metz of the Army War College says, "You have to remember that many consider international law to be a form of asymmetric warfare, limiting our choices, tying us down." Yet history tells us that, time and again, the society that builds an ethical rule of law and stands by its values is the one that ultimately prevails on the battlefield. There is a "bottom line" reason for why we should adhere to the laws of war, explains a U.S. Air Force major general. "The more society adheres to ethical norms, democratic values, and individual rights, the more successful a warfighter that society will be."

So as we begin to wrestle with the problems that robots present for the laws of war, we might find instructive the wisdom from a past generation that grappled with a revolutionary and fearsome new technology (in that case, atomic weapons). As John F. Kennedy said in his inaugural address, "Let us never negotiate out of fear, but never fear to negotiate."