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FORTUNE

INVASION OF THE SERVICE ROBOTS

Like human workers, robots are moving into services -- especially jobs people find dangerous or boring. Their boosters see a much bigger market than in manufacturing.

By
Gene Bylinsky REPORTER
Alicia Hills Moore ASSOCIATE
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(FORTUNE Magazine) – FOR A LONG TIME robots have been stuck on the factory floor, toiling away at such repetitious, brute-force chores as welding car bodies and lifting heavy steel bars. Now they're breaking loose. Like their human colleagues, they are moving increasingly from manufacturing into services.

For several years service robots have been at work in nuclear plants, where people risk exposure to radiation, and under the sea, where human divers require cumbersome and costly life-support systems. Today the protean machines are embarking on a multitude of new activities: taking care of the handicapped and elderly, picking oranges, cleaning office buildings and hotel rooms, guarding commercial buildings, even helping cops and brain surgeons.

Doctors at California's Long Beach Memorial Hospital have performed more than 20 delicate brain operations with the help of a robot arm that drills into the skull with great precision.

In Dallas a year and a half ago, police used a robot to bluff a suspect barricaded in an apartment into surrendering. When the robot broke a window with its scary mechanical arm, the man came running out the front door shouting, "What the hell was that?"

In U.S. laboratories, more than 1,200 robots perform such intricate tasks as weighing, measuring, and mixing minute quantities of chemicals, medications, and even DNA.

The Navy is starting to deploy undersea robots with lobster-like claws that snip the mooring cables of stationary mines, such as those currently threatening ships in the Persian Gulf. Other fields wide open for service robots include building and maintaining offshore oil rigs, working on construction sites, tending hospital patients, assembling space stations, pumping gasoline, preparing fast food, fighting fires, and inspecting high- tension electric wires.

"We're seeing the birth of a big, new industry," says Joseph F. Engelberger, 62, the father of industrial robotics and the principal driving force behind service robots. "Now that robots can be mobile and are starting to be able to see and feel, service jobs will eclipse the entire manufacturing scene for robotics."

He envisions service robots soaring to $2 billion in annual sales in the U.S. by 1995, up from about $120 million today, mostly in undersea applications. (Like many such estimates in high technology, that $2- billion figure may well be optimistic.)

By contrast, the U.S. market for industrial robots is expected to reach $370 million this year and $1 billion in the mid-1990s. As with almost any new technology, the major innovators aren't the big, established companies -- in this case industrial-robot makers GM Fanuc Robotics, IBM, and Cincinnati Milacron -- but small companies such as Engelberger's Transitions Research Corp. (TRC) of Bethel, Connecticut. (About the only exception is Westinghouse, which provides service robots for nuclear utilities.)

In the late 1950s Engelberger ignited the industrial robotics revolution by starting Unimation Inc., the first robot company. TRC, a three-year-old privately held company with annual sales of about $1.5 million, is Engelberger's entry in the service-robot sweepstakes. The last time around, the Japanese in effect stole Engelberger's baby, the industrial robot. Because he could not afford to patent his robot in Japan, they ran away with it by copying and mass-producing the machines. Japanese robot makers such as Fanuc and Matsushita now control the world industrial-robot market.

To keep the nascent service-robot industry from slipping into Japanese hands too, Engelberger has assembled an impressive lineup of big corporate backers for his projects, including Du Pont, 3M, Johnson Wax, Electrolux AB, Maytag, and Emhart, a Connecticut conglomerate that had $2 billion in sales last year. While Japan isn't exactly asleep, as of now it is behind in the underlying technologies. A VISITOR TO TRC can be greeted by a squat three-foot-tall robot, a test- bed for an automatic vacuum cleaner, rolling by Engelberger's office with its electronic innards exposed. Research on the vacuum cleaner is sponsored by Electrolux, the big Swedish consumer electronics concern. Designed to clean malls, supermarkets, factories, and airports without human assistance, it will sell for about $20,000 when it goes on the market next year. According to TRC, outside surveys show that a business with 35,000 square feet -- the size of a small shopping mall -- to clean could use the machine economically.

Other Engelberger robots include HelpMate, a nurse's aide that will deliver meal trays to bedridden hospital patients. Along the way, the wheeled robot will take elevators and negotiate hallways by itself, doubtless startling unwary visitors. HelpMate will be tested starting next January at the Danbury, Connecticut, hospital; Engelberger plans to put it into mass production in 1989. It will sell for about $25,000 and will pay for itself in 2 1/2 years if it is used 24 hours a day, according to TRC-sponsored studies. Engelberger's "ultimate robot," as he calls it, will be a $50,000 household helper -- assuming he can raise about $20 million to develop it. He sees this robot as a high-tech butler that would prepare meals, clean the house, cut the grass, clear the driveway of snow, and even fix household appliances such as refrigerators and washing machines. "You'll get value and return on investment compared with hiring a practical nurse at

$9 an hour to help your old mother get around the house, as I do now, for example," Engelberger says. One snag: He hasn't yet figured out how to teach it to make the beds. Not everyone agrees that an all-purpose household robot will work.

David Nitzan, director of the robotics lab at SRI International, thinks that it would make more sense technically to concentrate on single applications -- a bathroom-cleaning robot, for example. But no one disputes that service robots are expanding. Among other things, Nitzan and his group are working on the vision system for a robot that would automatically sort packages for the U.S. Postal Service. Why the service robot surge? For one thing, progress in core technologies -- vision, mobility, controls -- has been rapid.

"It's a golden time," says William Whittaker, a senior scientist at the Carnegie Mellon University Robotics Institute in Pittsburgh, a leading developer of service robots. "A couple of years ago my feeling was that there was very little insight into either what to do or how to do it. But now those contributing or enabling technologies are there for the most part. There's the magnitude of the market, the potential and the inevitability of the technologies. It's as foregone as computing was 20 years ago. It has the same feel to it."

There are demographic pressures as well. Many service-robot suppliers see the rapidly aging U.S. population as a huge, new market. People over 85 now make up the fastest-growing segment of the elderly in the U.S., and 200,000 older Americans a year break their hips. Says Karen G. Engelhardt, director of the Health and Human Sevices Robotics Laboratory at Carnegie Mellon: "Never before have we seen a technology with such promise and potential to help this large and growing population in ways they never could be helped before."

BECAUSE SERVICE ROBOTS are often able to make repairs under hazardous conditions faster than people can, for example, they may deliver the increased productivity that has generally eluded the service sector. Shortages of service workers such as nurses are another force driving the advent of service robots. So are corporate policies and regulatory pressures against placing workers in dangerous settings.

Since 1971, for instance, 54 deep-sea divers have been lost in North Sea offshore oil and gas operations. The shift toward robot submersibles has turned a lot of divers into shipboard robot operators -- a much safer occupation. In nuclear plants, robots toil for hours at a time in highly radioactive areas in place of hundreds of employees, called jumpers or glowboys, who worked in short relays so as to minimize their exposure. In space, robots can significantly speed assembly of big structures like NASA's projected space station for the 1990s.

In those three settings -- in nuclear plants, under the sea, and in space -- cost savings are a big factor as well. Supporting deep-sea divers and astronauts working outside their spacecraft can cost up to $100,000 an hour. When a nuclear plant shuts down, replacing the lost electricity can cost a utility an estimated $500,000 a day; robots have already helped shorten those shutdowns. The military, whose primary concern isn't economics, sees in the new robots a way to maintain high-tech superiority over more numerous enemy armies on a battlefield.

The Pentagon is spending hundreds of millions of dollars a year to develop small unmanned tanks, intelligent robotic undersea vehicles, and flying spy robots that fill the gap between airplanes and satellites. Robert Finkelstein, president of Robotic Technology Inc. of Potomac, Maryland, who works closely with the Pentagon, says research and development outlays for robot systems will soar to $3 billion a year by 1995.

Both robot builders and users now recognize that the new robots can do a lot of things humans can't. Anthropomorphism -- having robots imitate human activities -- has fascinated robot buffs ever since the Czech playwright Karel Capek introduced the word "robot" into the lexicon. In his popular 1921 play R.U.R., for Rossum's Universal Robots, Capek made robots look like mechanical counterparts of man. He derived the word from the Czech robota, which means work -- including forced labor.

Anthropomorphism is appealing, but many robot builders think it is usually a wrong track in robotics because it fails to take advantage of some remarkable man-made devices and technologies. Although highly dextrous, the human arm and wrist, for instance, cannot twist completely around. A robot hand can. "We can try all we want to imitate mammals," says TRC's Engelberger, "but no animal has a built-in ball bearing." A robot arm that rotates in all possible directions, for example, is more useful than an imitation human arm that is limited by its joints.

In a remarkable demonstration of robotic agility, a nuclear-plant robot built by Odetics Inc. of Anaheim, California, not only walks on six legs but also can extend itself from a height of five feet to a total of 14 feet, becoming a kind of a mechanical giraffe. It can hang from ledges inside nuclear plants, working upside down. By automatically changing the gripper in its hand it can do a variety of tasks, from changing light bulbs -- a huge job in a nuclear plant -- to lifting objects that weigh up to 300 pounds. Similarly, surveillance robots can do things a human guard cannot. Thanks to microwave vision, they can see through nonmetallic walls and in the dark can spot an intruder as far as 130 feet away.

Most robots in use today in space, under the sea, and in nuclear plants are operated from a distance by human workers as extensions of themselves. More often than not, the robots are tethered by a cable to the control station; the cable transmits electric power and serves as a communication link to the robot. Robot builders call this telerobotics, or teleoperation -- an extension of human sensing and manipulating capability.

WHILE TELEOPERATION obviously keeps people out of hazardous environments, it has drawbacks. Operators can have trouble controlling remote robots and monitoring exactly what they're doing -- for instance, when they're working undersea in murky waters. For greater versatility, a robot should work on its own, with minimal human supervision.

Says Robotic Technology's Finkelstein: "The essence now is intelligent control systems. The technology for teleoperation is here now. The technology for automatic operations is being developed. If you have a tank as smart as an ant that knows how to tell an enemy from a friend, that could revolutionize warfare."

Currently, the U.S. Army is developing a walking truck to traverse roadless terrain, a contraption with fat, bent legs and a wriggling body that make it look like an immense, unearthly insect. The growing military applications of robots promise civilian fallout that could pay off for companies big and small. For example, military work on robots that navigate by themselves could be applied to trucks, automobiles, and factory vehicles.

Early designs for NASA's space station assembly robot, called Flight Telerobotic Servicer (FTS), resemble a refrigerator with a flat head and four arms. FTS will be a hybrid between a telerobot and a fully autonomous machine. An astronaut can run it in two ways. In the teleoperated mode, the physical motions of an astronaut's hand will be reproduced by the robot's mechanical arms, which multiply the astronaut's force. The astronaut will work in shirtsleeves inside the space station; the robot will be outside. Alternatively, the robot could operate "teleautonomously." The astronaut would transmit complex commands for it to interpret and execute. The astronaut, for instance, could command the robot to repair a nearby spacecraft. The robot would dock with the satellite and do its job without any further commands from its operator, who would watch the robot on his TV screen and intervene if needed. Six NASA contractors -- Westinghouse, Grumman, Fairchild, Lockheed, Martin Marietta, and United Technologies -- have just submitted preliminary design plans for the FTS robot.

Giulio Varsi, manager of automation and robotics for NASA's space station office, talks enthusiastically about developing space robots that "learn as they go along" -- intelligent automatons with sufficient vision and a fine sense of touch that can modify their actions as circumstances change. Such technologies would help improve earth-based service robots. The initial FTS robot will cost about $200 million, in part because of its highly complex software, but subsequent versions could probably be produced for about $10 million apiece, Varsi says.

THE MOST SURPRISING demonstration of robot autonomy so far will take place as early as October at New Hampshire's Lake Winnipesaukee. In a game of wits, government and University of New Hampshire researchers will pit two untethered undersea robot craft working together against men in boats, who will try to detect the robots with sonar and other instruments. For their part the robots will work in tandem, using microprocessors guided by artificial intelligence software. The robot craft will attempt to elude their human pursuers by sacrificing one robot and having the other escape with TV pictures and other data it has gathered. The key to making robots smarter lies in computer power that can enhance their intelligence, which is so far rather dim. Carnegie Mellon's Whittaker says that some of the service robots his institute has built have only reached the "intelligence of a worm." Robots as brainy as the pair in Star Wars, the timid android C3PO and its barrel-shaped electronic sidekick, R2D2, are at least 50 years away.

One reason: Progress toward giving robots humanlike sight and hands has been excruciatingly slow. In the case of sight, digital computers have trouble recognizing patterns that people spot almost intuitively. After about a decade of work, researchers at Stanford University who are trying to impart vision to robots have just scored what they consider an impressive victory. Their vision system can recognize about two dozen different objects -- airplanes of varying shapes, for example -- as belonging to a single class. A University of Utah- MIT project in progress for seven years has yet to produce a fully workable hand, although researchers have constructed a

computerized prototype with tendon-like wires and four fingers run by 32 miniature motors. Both research teams have come to appreciate the awesome complexity of human senses and information processing.

Says Stanford researcher Thomas O. Binford: "The retina of one eye has roughly 100 million specialized vision cells and four layers of neurons, all capable of doing about ten billion calculations a second." All told, about 60% of the brain's cortex, the so- called thinking cap on top of the brain, is involved in handling visual information -- a computational task that it would take 100,000 Cray supercomputers to handle, Binford estimates. If researchers can get robots to see clearly and to understand where they are -- another classic problem -- that would make possible seeing-eye robots, among other things.

The elusiveness of perfection does not deter the practical types, however. "University researchers sometimes unnecessarily complicate things," says Engelberger. "We take bits and pieces of available technology -- ultrasound, infrared, TV cameras -- and we tell our robots beforehand where to go."

ENGELBERGER PLANS to get around the "Where am I?" problem in his cleaning robot by using what he calls the Hansel and Gretel concept. In a typical operation, the robot begins by circling the perimeter of a room, bouncing sonar off the walls to locate itself. As the robot goes along, the Hansel and Gretel scheme comes into play. Those fairy tale tots marked their path in the forest by leaving a trail of bread crumbs to guide them back out. Birds ate the crumbs, of course, or there wouldn't have been a story. Each time Engelberger's cleaner makes a circuit, it will drop tiny pieces of fluorescent paper -- "bread crumb equivalents," Engelberger calls them -- to one side, creating a parallel, inner circle that it will follow the next time around. It's much like mowing a lawn in a continuous spiral from the outside in. As the robot follows the path, its scrubbing brushes will clean up the old trail just as Hansel and Gretel's birds did. This or similar approaches are a lot easier than trying to build up a comprehensive picture of the world inside a robot's brain. As for hands: Many of today's robots can automatically change their "end effectors," tools that take the place of fingers to perform different jobs.

Odetics, the Anaheim company that builds the walking robot, has just developed a hand that can grip a wider variety of objects and shapes -- from a pencil to a railroad tie -- than other models. It has two thumbs and one finger; the thumbs can rotate to grasp a payload, just as human thumbs can. Unlike a human hand or the University of Utah-MIT design, the Odetics hand requires no "tendons" in the arm or wrist to provide the power to move.

AT CARNEGIE MELLON'S Robotics Institute, Bill Whittaker sees the next important advances in service robots coming not in the basic technologies that make the robots possible but in combining them into working robots. Putting that view into practice, his institute has been turning out an impressive flock of robots. One has been used to decontaminate radioactive parts of the disabled Three Mile Island reactor. Another, a hulking brute of a machine about the size of a compact car, has four wheels and four stiff legs to walk with if its steering or the motors that drive its wheels fail. It can work with a hook, a crowbar, a shovel, a saw, a water-jet cutter, and other tools it carries. Stanford University robot researchers have helped bring to fruition an impressive robot system that takes care of at least 13 needs of quadriplegics, from preparing

canned soup and serving it to brushing their teeth afterward. During a recent demonstration of its remarkable skills at the Palo Alto Veterans Administration Medical Center, the robot greeted visitors with a brisk "Hi, Earthlings!" and proceeded to put on an impressive show. Because the research has been financed with federal funds, the system is available to any company that wants to build and sell it. Stanford and VA researchers figure it can be built for about $50,000. What's coming will be even more surprising: smarter and even more mobile service robots that will be directed by a few simple words or even the gesture of a hand.

Says the ever visionary Engelberger: "The list of service applications will grow because some of the more stultifying, demeaning, and downright dangerous human activities are in the service jobs. Robotizing those jobs is both possible and economically justifiable. This is not just an extrapolation of industrial robotics but literally a new slave class -- mobile, sensate, service robots." Ready when you are, R2D2.

Robots for No Man's Land

Defense Companies Developing the 'Brains' to Remake War

By
Yuki Noguchi
Washington Post Staff Writer
Friday, January 30, 2004; Page E01

The education of Stryker, an 18-ton military monster truck, begins in the warehouse lab of General Dynamics in Westminster, Md.

There, Stryker, one of the U.S. Army's newest infantry vehicles, is fitted with a "ladar" scanner, the equivalent of a mounted pair of eyes that see by emitting 400,000 laser and radar beams and snap 120 camera images every second. Its brain -- a 40-pound computer system tucked inside its body -- processes that data, and makes instant judgments on how to act and where to go.

The eight-wheeled Stryker has already seen service in Iraq as an armored troop carrier with human drivers. The idea is to teach Stryker to accomplish a mission on its own, as a robot. By 2010, robotic Strykers and similar contrivances are slated to be in use as all-purpose battlefield vehicles, surveying battlegrounds, sniffing for land mines, or transporting supplies and troops to the front line.

An unmanned Stryker is part of the military's effort to move more machines into battle to save both money and lives. **"Well before the end of the century, there will be no people on the battlefield," said Robert Finkelstein, a professor at the University of Maryland's School of Management and Technology.**

Companies throughout the defense industry, among them United Defense LP of Arlington, Lockheed Martin Corp. of Bethesda and the smaller Gaithersburg-based Robotics Research LLC, are developing robotic systems to fill a variety of military functions. For General Dynamics' robotic systems department, making robot brains -- called autonomous navigation systems -- represents the largest business deal in the unit's 14-year history. In November, it won a $185 million award to develop between 30 and 60 automated-navigation prototypes that can be fitted onto vehicles of different size and function, not just Stryker vehicles.

Creating automated navigation systems for combat vehicles is part of the Future Combat System project to remake warfare. The Army plans to spend $14.78 billion on a new combat system over the next six years, of which autonomous navigation systems is one part, according to Maj. Gary Tallman, public affairs officer for the Army.

Founded in 1990 as F&M Manufacturing, the Westminster plant where Stryker's brain is being developed started out designing small, remote-controlled vehicles. Over time, the 80,000-square-foot facility made robots that sorted mail, read bar codes and packaged pharmaceuticals. General Dynamics purchased F&M, which employs 268 people, for an undisclosed amount of money in 1995.

Using autonomous machines in the military became possible in the mid-1980s, when computer processors became faster. In the 1990s, the development of improved sensor technology allowed machines to pick up more information about their environment. Now, autonomous systems can keep track of their whereabouts using global-positioning satellite links, and talk to comrades and commanders through wireless links that shut off automatically if the signal is in danger of being intercepted.

The first unmanned military vehicles made in the early 1980s by the Defense Department were huge vans the size of UPS delivery trucks, filled with hundreds of pounds of clunky computers that could barely navigate at 5 miles an hour in relatively flat terrain. By comparison, Stryker can navigate through forests and desert environments, or drive on the road at top speeds of 60 miles an hour.

Even with these developments, robots still have a lot to learn.

"Now, we have the basic functioning down, and we're trying to make it smarter at something, or better," said Chip DiBerardino, a senior engineer for General Dynamics who works on programming higher intellect into software.

One recent morning, DiBerardino tested a four-wheeled robot called MDARS (short for Mobile Detection Assessment and Response System), a robotic watchdog that patrols the Westminster lab's snow-covered back yard looking for "intruders." It drives several feet, eyes a parking sign and halts, apparently puzzled, until a human attendant reprograms MDARS to move on.

"Compared to a human, MDARS is really not that smart," DiBerardino says by way of explanation.

Developing a robot is like raising children, researchers say.

Even Stryker's most rudimentary movements require complex calculations that must be "taught" to its brain, using hundreds of thousands of programming codes and mathematical algorithms. When it hits a fork in the road, it selects the gravel route instead of the dirt track. When it finds itself trapped in a cul-de-sac, it backs up to reevaluate alternative paths. In the future, Stryker will learn more tactical behaviors mimicking a human's, like running and hiding in trees or behind hills in the presence of enemies. And if its automated comrades go down, it will learn to request orders to carry out an altered mission.

"We need to work on the nervous system of the robots, so it can really learn on its own by picking up patterns based on its prior experience," said Charles Shoemaker, chief of the Army Research Lab's robotics project office in Aberdeen, Md., which funds robotics research at General Dynamics and at universities and other government agencies.

The Predator unmanned aerial vehicle is the most visible of these efforts to have made it into combat. It debuted in Afghanistan and Iraq, collecting aerial images and sending them back to the home base. But autonomous navigation -- allowing an actual unmanned land vehicle that

thinks for itself to rove into battle situations -- is a taller order. It requires maneuvering around obstacles, ditches, signs and traffic, which are harder tasks to teach a machine.
Now that it can see and move, Stryker needs to learn how to perceive more and plan better, said James Albus, a senior fellow and researcher at the National Institute of Standards and Technology in Gaithersburg, which has helped develop some of the intelligence used in Stryker's brain.

"In a way, we're trying to duplicate the processes in the brain, and the brain's got a lot of little computers."

DID YOU HEAR? . . .

Washington Post, Monday, February 2, 2004; Page E02

"Well before the end of the century, there will be no people on the battlefield."

-- Robert Finkelstein, professor at the University of Maryland's School of Management and Technology, on General Dynamic Corp.'s new unmanned tank and other advances in military technology.

A New Model Army Soldier Rolls Closer to Battle

By
TIM WEINER
February 16, 2005 (NY Times, P.1)

The American military is working on a new generation of soldiers, far different from the army it has.

"They don't get hungry," said Gordon Johnson of the Joint Forces Command at the Pentagon. "They're not afraid. They don't forget their orders. They don't care if the guy next to them has just been shot. Will they do a better job than humans? Yes."

The robot soldier is coming.

The Pentagon predicts that robots will be a major fighting force in the American military in less than a decade, hunting and killing enemies in combat. Robots are a crucial part of the Army's effort to rebuild itself as a 21st-century fighting force, and a $127 billion project called Future Combat Systems is the biggest military contract in American history.

The military plans to invest tens of billions of dollars in automated armed forces. The costs of that transformation will help drive the Defense Department's budget up almost 20 percent, from a requested $419.3 billion for next year to $502.3 billion in 2010, excluding the costs of war. The annual cost of buying new weapons is scheduled to rise 52 percent, from $78 billion to $118.6 billion.

Military planners say robot soldiers will think, see and react increasingly like humans. In the beginning, they will be remote-controlled, looking and acting like lethal toy trucks. As the technology develops, they may take many shapes. And as their intelligence grows, so will their autonomy.

The robot soldier has been a dream at the Pentagon for 30 years. And some involved in the work say it may take at least 30 more years to realize in full. Well before then, they say, the military will have to answer tough questions if it intends to trust robots with the responsibility of distinguishing friend from foe, combatant from bystander.

Even the strongest advocates of automatons say war will always be a human endeavor, with death and disaster. And supporters like Robert Finkelstein, president of Robotic Technology in Potomac, Md., are telling the Pentagon it could take until 2035 to develop a robot that looks, thinks and fights like a soldier. The Pentagon's "goal is there," he said, "but the path is not totally clear."

Robots in battle, as envisioned by their builders, may look and move like humans or hummingbirds, tractors or tanks, cockroaches or crickets. With the development of nanotechnology - the science of very small structures - they may become swarms of "smart dust." The Pentagon intends for robots to haul munitions, gather intelligence, search buildings or blow them up.

All these are in the works, but not yet in battle. Already, however, several hundred robots are digging up roadside bombs in Iraq, scouring caves in Afghanistan and serving as armed sentries at weapons depots.

By April, an armed version of the bomb-disposal robot will be in Baghdad, capable of firing 1,000 rounds a minute. Though controlled by a soldier with a laptop, the robot will be the first thinking machine of its kind to take up a front-line infantry position, ready to kill enemies. "The real world is not Hollywood," said Rodney A. Brooks, director of the Computer Science and Artificial Intelligence Laboratory at M.I.T. and a co-founder of the iRobot Corporation. "Right now we have the first few robots that are actually useful to the military."

Despite the obstacles, Congress ordered in 2000 that a third of the ground vehicles and a third of deep-strike aircraft in the military must become robotic within a decade. If that mandate is to be met, the United States will spend many billions of dollars on military robots by 2010.

As the first lethal robots head for Iraq, the role of the robot soldier as a killing machine has barely been debated. The history of warfare suggests that every new technological leap - the longbow, the tank, the atomic bomb - outraces the strategy and doctrine to control it. "The lawyers tell me there are no prohibitions against robots making life-or-death decisions," said Mr. Johnson, who leads robotics efforts at the Joint Forces Command research center in Suffolk, Va. "I have been asked what happens if the robot destroys a school bus rather than a tank parked nearby. We will not entrust a robot with that decision until we are confident they can make it."

Trusting robots with potentially lethal decision-making may require a leap of faith in technology not everyone is ready to make. Bill Joy, a co-founder of Sun Microsystems, has worried aloud that 21st-century robotics and nanotechnology may become "so powerful that they can spawn whole new classes of accidents and abuses."

"As machines become more intelligent, people will let machines make more of their decisions for them," Mr. Joy wrote recently in Wired magazine. "Eventually a stage may be reached at which the decisions necessary to keep the system running will be so complex that human beings will be incapable of making them intelligently. At that stage, the machines will be in effective control."

Pentagon officials and military contractors say the ultimate ideal of unmanned warfare is combat without casualties. Failing that, their goal is to give as many difficult, dull or dangerous missions as possible to the robots, conserving American minds and protecting American bodies in battle. "Anyone who's a decision maker doesn't want American lives at risk," Mr. Brooks said. "It's the same question as, Should soldiers be given body armor? It's a moral issue. And cost comes in." Money, in fact, may matter more than morals. The Pentagon today owes its soldiers $653 billion in future retirement benefits that it cannot presently pay. Robots, unlike old soldiers, do not fade away. The median lifetime cost of a soldier is about $4 million today and growing, according to a Pentagon study. Robot soldiers could cost a tenth of that or less.

"It's more than just a dream now," Mr. Johnson said. "Today we have an infantry soldier" as the prototype of a military robot, he added. "We give him a set of instructions: if you find the enemy, this is what you do. We give the infantry soldier enough information to recognize the enemy when he's fired upon. He is autonomous, but he has to operate under certain controls. It's supervised autonomy. By 2015, we think we can do many infantry missions.

"The American military will have these kinds of robots. It's not a question of if, it's a question of when."

Meanwhile, the demand for armed bomb-disposal robots is growing daily among soldiers in Iraq. "This is the first time they've said, 'I want a robot,' because they're going to get killed without it," said Bart Everett, technical director for robotics at the Space and Naval Warfare Systems Center in San Diego.

Mr. Everett and his colleagues are inventing military robots for future battles. The hardest thing of all, robot designers say, is to build a soldier that looks and acts human, like the "I, Robot" model imagined by Isaac Asimov and featured in the recent movie of the same name. Still, Mr. Everett's personal goal is to create "an android-like robot that can go out with a solider to do a lot of human-like tasks that soldiers are doing now."

A prototype, about four feet high, with a Cyclops eye and a gun for a right arm, stood in a workshop at the center recently. It readied, aimed and fired at a Pepsi can, performing the basic tasks of hunting and killing. "It's the first robot that I know of that can find targets and shoot them," Mr. Everett said.

His colleague, Jeff Grossman, spoke of the evolving intelligence of robot soldiers. "Now, maybe, we're a mammal," he says. "We're trying to get to the level of a primate, where we are making sensible decisions."
The hunter-killer at the Space and Naval Warfare Systems Center is one of five broad categories of military robots under development. Another scouts buildings, tunnels and caves. A third hauls tons of weapons and gear and performs searches and reconnaissance. A fourth is a drone in flight; last April, an unmanned aircraft made military history by hitting a ground target with a small smart bomb in a test from 35,000 feet. A fifth, originally designed as a security guard, will soon be able to launch drones to conduct surveillance, psychological warfare and other missions.

For all five, the ability to perceive is paramount. "We've seen pretty dramatic progress in the area of robot perception," said Charles M. Shoemaker, chief of the Army Research Laboratory's robotics program office at Aberdeen Proving Grounds in Maryland. That progress may soon allow the Army to eliminate the driver of many military vehicles in favor of a robot.

"There's been almost a universal clamor for the automation of the driving task," he said. "We have developed the ability for the robot to see the world, to see a road map of the surrounding environment," and to drive from point to point without human intervention. Within 10 years, he said, convoys of robots should be able to wend their way through deep woods or dense cities. But the results of a road test for robot vehicles last March were vexing: 15 prototypes took off across the Mojave Desert in a 142-mile race, competing for a $1 million prize in a Pentagon-

sponsored contest to see if they could navigate the rough terrain. Four hours later, every vehicle had crashed or had failed.

All this raises questions about how realistic the Army's timetable is for the Future Combat Systems, currently in the first stages of development. These elaborate networks of weapons, robots, drone aircraft and computers are still evolving in fits and starts; a typical unit is intended to include, say, 2,245 soldiers and 151 military robots.

The technology still runs ahead of robot rules of engagement. "There is a lag between technology and doctrine," said Mr. Finkelstein of Robotic Technology, who has been in the military robotics field for 28 years. "If you could invade other countries bloodlessly, would this lead to a greater temptation to invade?"

Colin M. Angle, 37, is the chief executive and another co-founder of iRobot, a private company he helped start in his living room 14 years ago. Last year, it had sales of more than $70 million, with Roomba, a robot vacuum cleaner, one of its leading products. He says the calculus of money, morals and military logic will result in battalions of robots in combat. "The cost of the soldier in the field is so high, both in cash and in a political sense," Mr. Angle said, that "robots will be doing wildly dangerous tasks" in battle in the very near future.

Decades ago, Isaac Asimov posited three rules for robots: Do not hurt humans; obey humans unless that violates Rule 1; defend yourself unless that violates Rules 1 and 2.

Mr. Angle was asked whether the Asimov rules still apply in the dawning age of robot soldiers. "We are a long ways," he said, "from creating a robot that knows what that means."

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Battlefield robots are being readied to fight our wars, save human lives

COX NEWS SERVICE

WASHINGTON — Robot soldiers being developed by the Pentagon may invade hostile terrain, shoot enemies and care for wounded human comrades within the next decade, defense analysts say.

Some warn that the rapidly approaching era of robots able to operate independently on the battlefield will change the relationship between armies and societies, making it possible for advanced industrial nations to wage war without the human pain and sadness that for centuries have helped check war-making impulses.

Robots play key roles in the Army's $160 billion Future Combat Systems initiative, which aims to deploy armies that are agile and lethal.

Some robots and unmanned aircraft already are being deployed in Iraq and Afghanistan, and every week the Pentagon announces new contracts.

Last week, the Army announced it was extending research and development work by scientists at Car-negie Mellon University on robot war teams.

Confronting "unknown opponents," each machine in such a team keeps track of its own movements and those of its teammates and makes decisions on its own, according to progress reports that researchers at the Pittsburgh university have submitted every few months to the Defense Advanced Research Projects Agency.

Veteran weapons analyst John Pike says the era of robotic warfare is approaching faster than most people realize.

"We are probably seeing the last manned tactical fighter being built now, and in a few years there will be no manned tanks or artillery," said Pike, director of the nonprofit think tank globalsecurity.org.

"By the end of the century there will be virtually no humans on the battlefield," said Pike. "Robots do what you tell them and they don't have to be trained."

He added: "If they are damaged, you can recycle their parts or take them to a repair shop. There is no condolence letter or funeral."

Projects that other contractors are working on include:

- Big Dog, a quadruped robot that walks like an animal over all types of terrain and carries up to 200 pounds on its back.
- RHex, a small six-legged robot that swims, walks and climbs stairs.
- RISE, a climbing robot that can shinny up trees or brick walls.
- The WASP, a hand-launched, half-pound surveillance aircraft with a 16-inch wingspan and a pair of color video cameras.

Some analysts predict that within 20 years, robots will think and act completely autonomously.

"I have a feeling that if there is consistent funding for research and development, there can be a robot cognitively as good as humans (at fighting on a battlefield) somewhere between 2020 and 2030," said Robert Finkelstein, president of Robotic Technology Inc. in Potomac, Md.

Finkelstein predicts that robots will unlock doors with keys, load, aim and shoot rifles within the next five years and will administer injections, carry soldiers to safety and perform tasks like changing a tire in 10 years.

But he said he worries that it may become easier to "interfere in other countries when parents are not yelling about the human casualty count."

He also wonders about the political consequences when "First World countries assemble robot armies, but Third World countries still use humans."

Others, such as Georgia Tech robotics expert Ronald Arkin, disagree.

"Robots behave more humanely in battlefields than humans because they are not concerned with their own destruction," Arkin said, and because their judgment is not clouded by anger.
Arkin is developing an artificial conscience mechanism to govern a robot's behavior during warfare.

Life imitates sci-fi in march toward robot soldiers

Plans pit ending pain vs. making conscience casualty

By
ALLISON BECKER

Cox News Service
Monday, July 09, 2007

WASHINGTON — Robot soldiers that the Pentagon is developing may invade hostile terrain, shoot enemies and care for wounded human comrades within the next decade, defense analysts say.

Some warn that the rapidly approaching era of robots able to operate independently on the battlefield will change the relationship between armies and societies, making it possible for advanced industrial nations to wage war without the human pain and sadness that have helped check war-making impulses for centuries. Robots play key roles in the Army's $160 billion Future Combat Systems initiative, which aims to deploy armies that are agile and lethal. Some robots and unmanned aircraft are being deployed in Iraq and Afghanistan, and the Pentagon announces new contracts every week.

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- RISE, a climbing robot that can shinny up trees or brick walls.
- The WASP, a hand-launched, half-pound surveillance aircraft with a 16-inch wingspan and a pair of color video cameras.

"We spend a lot of time talking to the Department of Defense to get an idea of its needs. At the same time we are listening to the technical community," said Jan Walker, a spokeswoman for the research agency.

The agency is working on a surveillance plane that would weigh less than a half-ounce and have a wingspan of only about 4 inches, she said. Another program aims at giving machines the ability to detect and intercept incoming bullets.

Some analysts predict that robots will think and act completely autonomously within 20 years.

"I have a feeling that, if there is consistent funding for research and development, there can be a robot cognitively as good as humans" in fighting on a battlefield somewhere between 2020 and 2030, said Robert Finkelstein, president of Robotic Technology Inc. in Potomac, Md.

Finkelstein predicts that robots will unlock doors with keys, load, aim and shoot rifles within the next five years, and they will administer injections, carry soldiers to safety and perform tasks such as changing tires in 10 years.

During the past decade, robot researchers have improved computational power, situational awareness, path planning capabilities and object recognition, Finkelstein said.

But he said he worries about the effect the technological changes will have on an unstable world.

He thinks it may become easier to "interfere in other countries when parents are not yelling about the human casualty count."

He also wonders about the political consequences when "First World countries assemble robot armies, but Third World countries still use humans."

Yet images of remorseless machines charging across the countryside, laying waste to life and property in the manner of Transformers, may not be realistic, says Georgia Tech robotics expert Ronald Arkin.

"Robots behave more humanely in battlefields than humans because they are not concerned with their own destruction" and because anger does not cloud their judgment, Arkin said.

Arkin is developing an artificial conscience mechanism to govern a robot's behavior during warfare. This mechanism is based on "laws of war, codes of conduct and rules of engagement," such as the Geneva Conventions and international protocols.

"I have stacks of documents going back to the 1200s," Arkin said. "But the real question is making systems comply as well as soldiers."

The proliferation of military robots and robot research has raised a variety of unexpected issues. In a public opinion survey, Arkin asks people about who assumes responsibility if robots are released into the battlefield and something goes wrong.

"The result of this survey will allow us to determine who is at fault," Arkin said. "Is it a robot itself, a commander, politicians, researchers ... One of the things that is very important in just warfare is establishing responsibility for the use of weapons systems."

Although robots may function without human emotions, problems may develop when humans become "attached" to robots, he said.

An example, he said, was the reaction when a video of Big Dog was posted on the Internet. To demonstrate the machine's ability to recover when attacked, an attendant is shown kicking it in the side. The mechanical pack mule stumbles, adjusts and plods on.

Some viewers expressed outrage at the mistreatment of the machine, Arkin said.

Getting robots of war to act more naturally

Researchers look to swarms and colonies.

By Faye Flam
Inquirer Staff Writer
Philadelphia Inquirer, Jun. 12, 2008 (Front Page)

The next generation of military robots won't just be humanoids like the Terminator.
The robots of the future will likely work in concert, like a swarm of ants. Others may creep like spiders or hover like hummingbirds, if the work at the University of Pennsylvania is an indication.

Most of the more than 5,000 robotic devices now in Iraq are remote-controlled, sniffing out explosives or performing other jobs with constant human instructions.

But in a shift with huge implications for warfare and diplomacy, the military wants robots that act on their own volition. It's a prospect that promises to save lives, but could also make wars more palatable and easier to start, some experts say.

"The key [to the new robots] is increasing autonomy," said Joseph Mait, senior technical researcher at the U.S. Army Research Lab in Adelphi, Md. "Now we have several soldiers per robot, but in the future we'd like to have one soldier with many robots."

In one futuristic scenario, Mait said, soldiers faced with kicking down a door would instead send in a team of robotic scouts with specialized roles. "One may be a flier, two others crawlers, and yet another may have the ability to perch," providing perspective from above, he said.

To realize ideas like these, the military is offering millions of dollars in grants to the country's premier research labs. Two were awarded this spring to engineers at Penn's robotics lab - known as GRASP (General Robotics, Automation, Sensing and Perception). Last spring, the group won the biggest grant in the engineering department's history - $22 million - to make robotic versions of ants, flies, cockroaches, or some combination of insects capable of self-direction and cooperation.

In a recent demonstration at the GRASP lab, an octet of wheeled robots the size of paint cans circled and closed in on an L-shaped block, and then ferried it away in minutes, like ants with a picnic scrap. Each robot drinks in a stream of data on its neighbors' movements, and then acts on the information spontaneously.

"We're following nature," said Penn engineering professor Vijay Kumar. In his office, he reaches for a copy of National Geographic, showing a colony of black ants, crawling over one another and creating a bridge with their bodies.

"Each ant is pretty stupid," he said. But something in their communication allows them to kill prey and move objects many times their size.

One key feature of ant colonies is that they are decentralized, he said. "Ants and bees don't have to be controlled."

Another insect trait researchers are trying to copy is how worker bees are replaceable. The destruction of one or two won't hold back the swarm.

Some of the smartest-acting swarms have no leader, Kumar said, and no specialized roles. Instead, they follow a few rules that add up to complicated behavior.

The researchers aren't limiting themselves to ants, said Penn engineer George Pappas. They also are looking at wolves, dolphins and humans to see how different robots might cooperate.
In one wing of the lab, graduate students Nathan Michael and Jonathan Fink were testing rolling robots the size of toy trucks.

The hard part is figuring out what simple rules the robots should follow, Michael said. "We measure everything that's happening at an excruciating level of detail."

Scientists are already used to thinking of swarm behavior as potentially intelligent.
"Intelligence is not the sole province of human beings," said robot engineer Ron Arkin of Georgia Tech, who is collaborating with Penn professors. A desert ant, he said, is smart at living in the desert.

In another imitation of nature, one company is developing robots that fuel up like animals. The idea is to make them extract energy from foliage, said Robert Finkelstein, president of Robotic Technology Inc. in Potomac, Md.

Arkin said the demand for robots' independence comes partly from the increasing speed of warfare. In World War II, he said, you saw a radar blip and had time to call the commander. "Now you have just minutes to make a decision."

In another part of Penn's robotics lab, a robot about the size of a Chihuahua negotiates a stretch of treacherous rubble. "That's Little Dog," said Kostas Daniilidis, an engineering professor at Penn.

The spindly-legged, headless device looked more insectlike than canine. Off to the side were some of Little Dog's other challenges - a stretch of fake cobblestones and something like a bumpy wooden bridge.

Daniilidis and the other Penn engineers say they envision lifesaving applications for their work. "Imagine you have something like ground zero," Daniilidis said. Robots faster than humans could sift through debris looking for survivors.

But could someone program robots to kill people?
"It's a very difficult question," Daniilidis said. "Engineers should be involved in the discussion because they can define where the autonomy boundary is."

John Pike, a weapons analyst and director of GlobalSecurity.org, said the engineers were being naive about the long-term use of their work.

"No one's really thought through where this might be heading, and you're certainly not going to get those nice engineering-school people to talk about it. . . . They only make nice robots."
Look at who pays for their research, he said, referring to military agencies. "The profession of arms is about killing the enemy." Most flesh-and-blood soldiers, he said, may be reluctant to kill. According to studies, he said, "two-thirds of the people who sign up for the military aren't capable of killing." They either fail to fire or simply spray bullets wildly.
Robots would have no such reservations, he said. "They will be stone-cold killers and they will be infinitely brave."

"The bad news is we'd be a rogue superpower going around blowing everyone up," he said. "On the other hand, we could end genocide" without having to sacrifice thousands of American lives.

Finkelstein of Robotic Technologies foresees robots replacing people in many commercial applications. He envisions robots driving cars, and far more safely than humans.
And other countries will develop fighting robots. "Then you're into a technological arms race," he said.

Georgia Tech's Arkin has been writing and speaking on what he calls robo-ethics. The most important consideration, he said, is to hold onto today's ethical principles - "what humanity has deemed ethical behavior."

That means the use of appropriate weapons - "not nuking people back to the Stone Age - and it means no unnecessary suffering." Technically, he said, robots could be programmed with certain constraints.

"I'm happy to assist our war fighters with the best technology we can deliver them," he said. "But I want to make sure we're not selling our souls in the process."