Draper's Spike – an early throwable bot – paved the way for smaller and smarter roving reconnaissance machines.

THE NEW MOBILE INFANTRY

Battle-ready robots are rolling out of the research lab and into harm's way.

By Michael Behar

Illustrations by Martin Woodtli

Lieutenant Colonel John Blitch retired from the Army last fall, filling out the paperwork in an out-processing office of the Pentagon on the morning of September 10, 2001. In his three years at the helm of the Defense Department's Tactical Mobile Robots Program, Blitch had funded nearly a dozen academic and corporate research efforts. Their goal: building bots to replace human soldiers and rescue workers in dangerous situations. Barrel-chested and brawny, the 43-year-old Special Forces officer was leaving to direct the Center for Intelligent Robotics and Unmanned Systems at the Science Applications International Corporation, an engineering outfit and defense contractor in Littleton, Colorado. He planned to start the 1,500-mile drive the following day.

With news of the terrorist attacks, though, Blitch scrapped the trip. He removed his belongings from the flatbed trailer hitched to his pickup, loaded up a set of tactical mobile robots, or TMRs – most about the size of a football and fitted with rugged treads and an assortment of sensors – and headed for New York. On the road, Blitch donned his fatigues, dug out his military ID, and worked his cell phone, summoning colleagues from Florida to Boston to pack up their finest tactical robots and rendezvous at Ground Zero. "When I arrived, we passed through 32 checkpoints," he recalls. "People were asking, 'Who is this guy in camouflage running around with grad students and robots?'"

Over the next 11 days, the group's 17 robots squeezed into spaces too narrow for humans, dug through heaps of scalding rubble, and found seven bodies trapped beneath the mountains of twisted steel and shattered concrete. While that was only a tiny portion of the 252 victims recovered by rescue workers, the success triggered a deluge of fawning press ("AGILE IN A CRISIS, ROBOTS SHOW THEIR METTLE," announced *The New York Times*. "ROBOTS HELP WHERE HUMANS FEAR TO TREAD," echoed the *Houston Chronicle*). The publicity helped Blitch avoid a berating from his superiors for skirting regulations and passing off specious credentials (technically, he was retired).

More important, the mission proved the viability of Blitch's grand ambition: "to build robots that can do things human soldiers can't do, or don't want to do." Although the machines at Ground Zero were used for search-and-rescue, the real-world test reinvigorated researchers developing more versatile soldier robots to handle reconnaissance, live combat, and all-purpose warfare.

While robotic research has been trudging forward for nearly a half century, TMRs are a fairly recent innovation. Darpa launched its program in 1997 under the leadership of Eric Krotkov, a former Carnegie-Mellon roboticist and an expert in planetary rovers. Krotkov signed up the first 10 contractors for an initial five-year, $50 million initiative. Blitch took over one year later, funding 25 major projects and more than a dozen smaller ones – all told, they produced 43 prototypes and 18 unique robots.

Today, more than 40 Darpa-backed companies and academic labs are developing robots. There are recon machines that can be air-dropped into enemy territory and relay back intelligence data in real time. There are 3-pound surveillance bots that frontline soldiers could lob through a window or around a corner to get an audio and video preview of conditions. There are robots that can negotiate harsh terrain, scurry up stairs, or rush into battle to rescue injured soldiers pinned down by heavy shelling or gunfire. Other machines in development can carry weapons, deliver jolts of electricity, sniff for biogerms, and see through walls. There's even a walking robot, which could lead soldiers around blind corners, drawing fire from potential snipers. "We needed one of those in Somalia," says Blitch as he watches a demo video of the biped bot that's been spliced with gory scenes from *Saving Private Ryan*.

War is dangerous and bloody, and no robot can fundamentally change that. But the generation of tactical mobile robots now in development promises to help soldiers and save lives by taking on the tasks that Michael Toscano, coordinator for the Joint Robotics Program at the Pentagon, sums up as "dirty, dangerous, and dull."

From the outside, the SAIC Center for Intelligent Robotics and Unmanned Systems hardly looks like the home of a highly advanced platoon of military machines. The lab butts up against Colorado's Front Range on the outskirts of Littleton, about 15 miles southwest of Denver. It's one of several offices in a rectangular brick structure that could easily be mistaken for a vacant strip mall. The place is eerily silent. A tumbleweed is lodged under a rusty truck in the parking lot. A wild hare darts through the blond grass. The windows are tinted, blinds shuttered.

"We picked the building because the bad guys would never suspect we are doing such sensitive work inside," explains Blitch, who's standing in his office. He's wearing a neatly pressed white oxford shirt tucked into faded black Levis.

His hair, which has receded a bit, is close-cropped and spiky in front. Blitch bolts down the hallway and through a steel door into a 3,000-square-foot high bay stocked with electronics and metallurgy equipment. There are at least a half dozen robots positioned around the room with technicians tending to each.

Jim Hamilton, a software engineer, demonstrates the lab's prize work in progress, a prototype TMR that's part of SAIC's Raptor (short for robotic autonomous perception technology for off road) project. Raptor can function as part of a marsupial system, a concept he's been developing since 1995. "We wanted to penetrate a bunker, but the robot, called Goldie, was too large to fit inside," says Blitch. "So we placed a smaller tethered robot on top of her, and when Goldie got close enough we drove the second one off and into the bunker." The Raptor project, launched in 2001 with Darpa funding, will eventually include a small team of marsupial robots with a Raptor vehicle acting as the mothership. Troops will be able to air-drop Raptor into enemy territory, where it will release a team of smaller, roaming "munitions bots," or M-bots. These roamers will relay data back to the mother bot, which aggregates the information and transmits it wirelessly. The first ground-to-ground-to-air marsupial system, Raptor will give the military a way to scout behind enemy lines and gather strategic information, an assignment often carried out by a squad of paratroopers outfitted with night vision equipment, walkie-talkies, and M16s.

That's the hope. But the only territory the Raptor prototype searches these days is the SAIC parking lot. The prototype is built atop a commercial all-terrain vehicle, though if the robot is approved for military production it will be upgraded for battle with a low-profile, heavily armored exterior. Hamilton turns on the gas-powered Raptor with what looks like a car key (the next version will have an automated startup), programs a route via laptop, and uploads it wirelessly to the TMR. The machine gracefully motors around the parking lot, following Hamilton's choreographed movements. For manual steering, he employs an off-the-shelf Logitech joystick. Eventually, Blitch wants to create a digital glove that would allow soldiers to execute commands using American Sign Language: "You want to be able to hold your weapon in one hand and control the robot with the other," explains Blitch. Images and sounds from as many as 30 onboard sensors – including infrared, night vision, digital cameras, directional microphones, GPS, and laser radar for making detailed 3-D maps of almost any terrain – will transmit data over a wireless LAN to a display in the soldier's helmet. At the same time, M-bots will send their findings back to a Raptor vehicle so the incoming information can be assembled into a detailed real-time rendering of the targeted area and uploaded to a satellite.

Tactical robot efforts at other R&D centers are no less impressive. Since 2000, scientists at Draper Laboratory, in Cambridge, Massachusetts, have been working on a series of throwable robots – small, lightweight rovers that can be tossed into hostile settings. "Let's say I'm trying to see who's inside a building before I enter," says Rob Larsen, a program manager at Draper. "I can pitch the robot like a baseball through a window. As soon as it hits the ground, it begins relaying video and audio." Essentially, a throwable bot gives a soldier X-ray vision and superhuman hearing. Says Larsen: "Troops now in the jungles of the Philippines would be able to know what's ahead of them with this technology."

The first throwable robot effort, funded by Blitch's TMR program, culminated in Spike – a grapefruit-sized bot that slides open and extends spiked wheels on command. Spike had no onboard sensors or processor and had to be tele-operated by a soldier using a wireless joystick.

Now, with funding from a different Darpa program, Draper is working on a more intelligent device called the high-mobility tactical microrobot, or HMTM. Larsen plans to have a prototype ready for Darpa in December and aims to supply a $5,000 battle-ready model within three years. But first, his team must devise a way for the HMTM to handle conditions as varied as mud, gravel, and water. One possible solution uses a hybrid motion system that switches between tanklike treads and wheels depending on the terrain. Larsen also needs to ensure that the device will be able to withstand repeated drops onto pavement. To that end, he's developing special impact-resistant materials to fortify the housing, wheels, chassis, and drivetrain.

In the meantime, the Draper group has written custom software that can compress video in real time. This feature will be particularly important when Larsen converts the communications system from its current 802.11b protocol to cellular, which can cover a broader geographical area (and is more suitable in remote locations) but operates over a narrower slice of bandwidth. No wireless system is 100 percent dependable, though, so Larsen is developing a homing instinct that he calls automatic retrotraverse. An onboard sensor tracks the HMTM's heading and wheel rotation. If the network fails, the robot can play back its movements in reverse, retracing its steps until communication is reestablished. "This will save the robot if the communication link with the operator drops out or is jammed," says Larsen. "It could spell the difference between mission success and failure."

The throwable microbot in development would give a soldier X-ray vision and superhuman hearing.

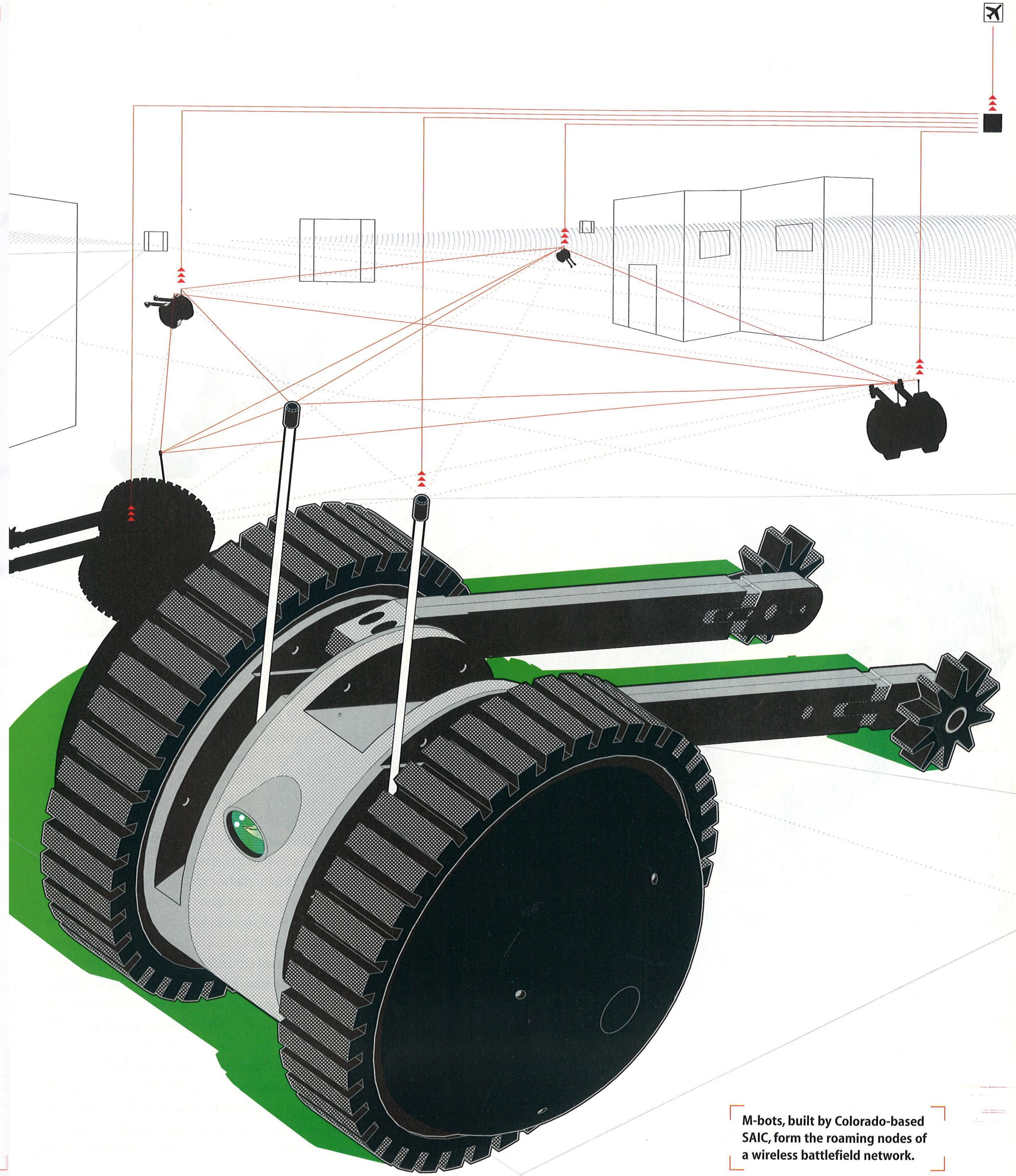
A few miles from Draper Lab, at an MIT spinoff called iRobot, researchers are developing another promising TMR: the PackBot. It looks like a miniature tank stripped of its gun turret and stands out for both its agility and versatility. The general-purpose TMR can be used as a workhorse vehicle for hauling ordnance or as a mobile first-aid station, dashing into battle with a cartload of medical supplies. In one video demo, the PackBot rescues an injured soldier lying between two buildings as bullets whiz overhead. The PackBot zips to his side, dragging a stretcher. The soldier rolls onto it. Medics, holed up in a nearby bunker, grab a tether attached to the stretcher and pull it to safety. In another clip, the PackBot ascends a flight of stairs in a couple of seconds. The iRobot engineers are working on teaching the PackBot to ford a river after looking for shallow water or protruding stones.

The robot is also wired for reconnaissance missions. "It has six payload sockets," says project manager Tom Frost. Each robot can handle 12 video sources, six Ethernet connections, eight USB ports, digital signal processing, and eight power supplies. A 700-MHz Pentium III with 256 Mbytes of memory, 300 Mbytes of storage, and two video cards crunches incoming sensor data. Finally, a digital compass and a GPS receiver keep the PackBot on course when it's in the field.

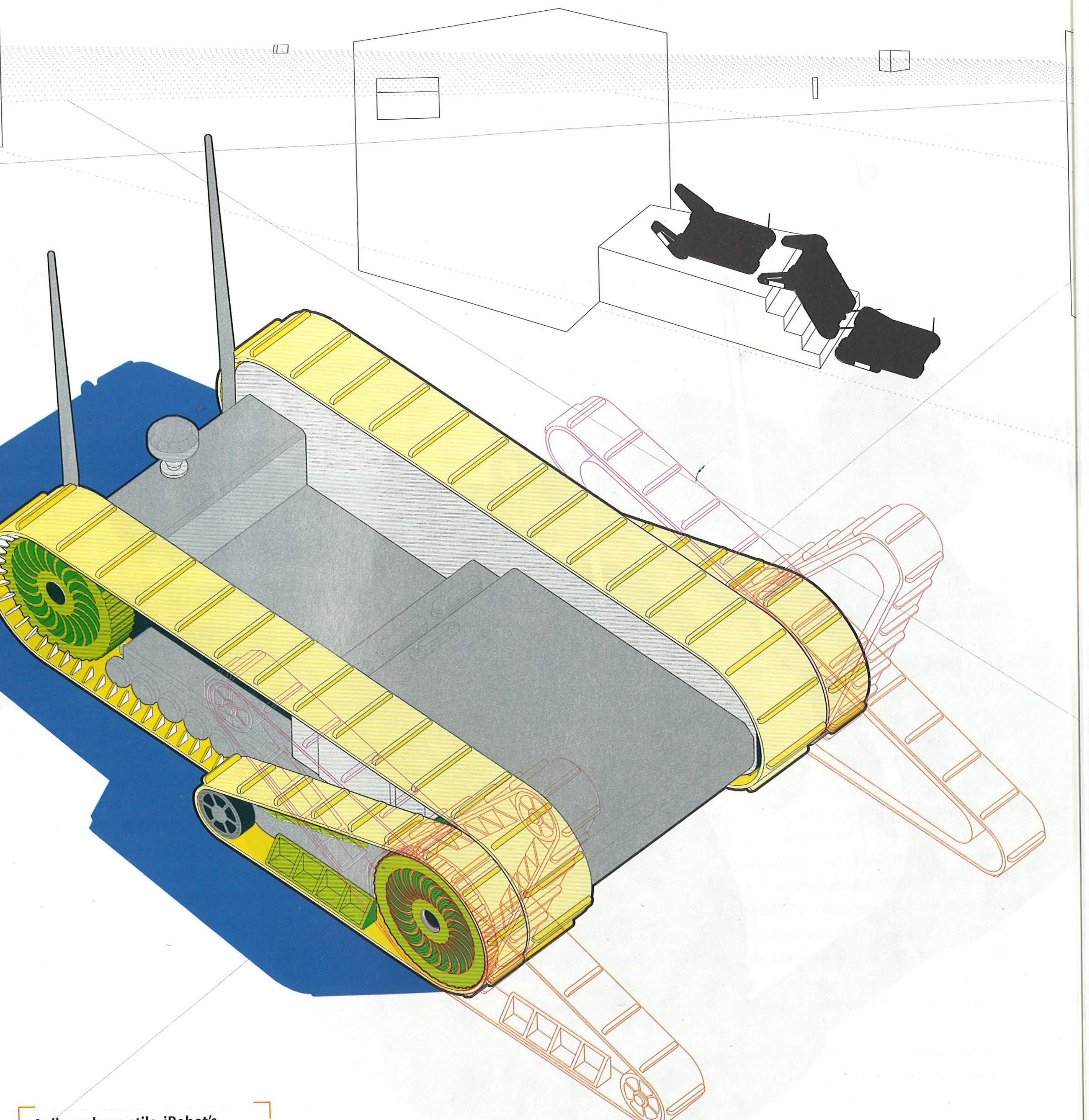
This summer, iRobot will deliver up to 15 PackBots – running $20,000 to $50,000 each – to the Department of Defense, which will distribute the machines for testing by various groups within the military.

The PackBot, the HMTM, and all of the SAIC devices were funded by Darpa and guided by what those in the industry know as Blitch's Five Imperatives:

Michael Behar (michael@michaelbehar.com), a former senior editor at Wired, writes about science and technology in Washington, DC.



M-bots, built by Colorado-based SAIC, form the roaming nodes of a wireless battlefield network.



Agile and versatile, iRobot's all-purpose PackBot can ascend a flight of stairs in seconds.

A TMR must be able to get back on its feet when it has fallen. It must be able to recover from communication loss. It must know where it is. It must be tamper-proof. And it must be able to maneuver around complex obstacles.

According to Blitch, no single tactical robot meets all five imperatives yet. But he has seen a steady evolution. "First you had radio control," he says, "where there was a full view of the vehicle at all times, and you dictated its every move." Next came tele-assisted bots, which are still guided by a human but can venture out of sight because they employ video, audio, and other sensory feedback. Tele-operated units can maneuver independently, asking questions only when they are confused. The final step, says Blitch, is complete autonomy, meaning that the robot will carry out a mission according to a set of predefined parameters, without step-by-step human guidance.

Watch Raptor move around the SAIC parking lot – controlled by Jim Hamilton and a laptop, and chased by an engineer ready to yank out the power cord if things go wrong – and you know that complete autonomy is a few years away. Currently, a typical TMR requires three or four handlers. Ultimately, researchers want to invert the ratio, allowing one soldier to control multiple autonomous robots. "Then you've achieved force multiplication," says Ron Arkin, a professor of artificial intelligence, computer vision, and mobile robotics at Georgia Tech who's written software for the Darpa program. "You could have 10 people on the battlefield doing what once took 40 soldiers."

The PackBot would have been handy at Hue City, says a vet – or scouting Vietcong tunnels.

The biggest challenge between, say, the PackBot and complete autonomy is software. It's easy enough to add another sensor; it's much harder for the robot to know how to interpret the data that sensor collects *and* how to integrate it with other incoming data. A tactile sensor, for instance, can "feel" uneven terrain using a series of predetermined algorithms. When the TMR discovers it's driving over rough ground, it reduces speed. Now, imagine that while the bot's sensors are detecting and responding to the surface, other sensors realize that the robot is being shot at. Should it continue slowly or speed away?

Hamilton is developing a software suite that can accept input from dozens of sensors and decide on the best course of action. Analogous to the human brain, ATAC (autonomous terrain adaptive classifier) employs an arbitrator that examines the incoming data – which might indicate gunfire, darkness, water, bioweapons, or irregular topography – and decides whether to stay and fight or run for the hills. When Hamilton sketches ATAC's decisionmaking process onto a whiteboard in the SAIC conference room, the diagram resembles the schematics of a Ponzi pyramid. At the base, there's an array of sensors, each uploading data to the next level. A more sophisticated bank of sensors at the pyramid's midsection sifts through the raw data and generates a finite set of directives. Finally, at the top, ATAC evaluates the refined readings and makes an "educated" judgment.

There are plenty of critics who doubt that software solutions like ATAC will match the decisionmaking power of the human brain anytime soon. "Autonomous robotic weapons won't demonstrate human intelligence until machines pass the Turing test," says Ray Kurzweil, author of *The Age of Spiritual Machines*. Other naysayers point to more basic hardware problems that must be solved.

Most TMRs are smaller than tanks and less agile than humans, which can turn a molehill into a mountain. "The current wheel and track technologies are going to run into limitations," says Prasanna Mulgaonkar, the director of SRI's Advanced Automation Technology Center. He proposes a biomimetic solution: They could hop or slither or fly. Power is another stumbling block, which Georgia Tech's Arkin hopes fuel cells might solve.

"I still have not seen anything that can go where I had to go in Vietnam," says Bill McBride, a retired Marine lieutenant colonel who ran reconnaissance missions along the DMZ. McBride is a principal engineer at the Southwest Research Institute in San Antonio, Texas, where he runs the country's only independent test facility for tactical robots

Evaluators race the robots in circles on a 6,000-foot paved track until the bots either break or run out of juice. "Only when they survive the on-road track do we take them on the harder stuff," says McBride, whose offroad course includes a variety of mud bogs, water obstacles, steep culverts, rock beds, and a series of movable ramps covered with sand, gravel, and loose pipes. With each successive generation of tactical robots, McBride adds new challenges to the course. He's developing an experiment that will test how well the robots can avoid detection by a pack of aggressive dogs.

"In order to fit a TMR in your pack, you have to take out something – like ammunition – so the trade-off better be worth it," says McBride, who seems skeptical that the machines will ever be good enough. Nevertheless, he admits that a PackBot might have been handy in the battle for Hue City, a bloody house-to-house fight that cost 142 American lives and left 847 wounded. "We took a lot of casualties just trying to cross the street," says McBride.

That thought is echoed by retired colonel Mac Dorsey, who's now a program manager at Systems Planning Corporation, which provides technical and logistics support to Darpa's TMR program. As Dorsey says, "Using robots to search Vietcong tunnels would have been a much better solution than the state-of-the-art technology at the time – a very gutsy soldier."

While useful for discrete tasks, robots will never replace the well-trained soldier. "I think of them in the way a soldier thinks of his rifle: If it helps him or her get the job done, great. If not, leave it at home and take something else," says Scott Fish, the program manager of Darpa's Tactical Technology Office.

Blitch agrees that robots will never replace humans. "We are risk junkies," he says, arguing that soldiers want to be thrown into danger, not kept out of it. Still, looking at the TMRs in development today and listening to the scenarios of Blitch and other researchers, it's easy to imagine battlefields where soldiers are rarely placed in harm's way. And that makes you wonder whether we will be more inclined to go to war knowing there's less chance of losing human lives. When I ask Blitch if the robots will encourage violent solutions to political conflicts because – like the cruise missile or B-2 stealth bomber – they'll disengage us from killing, he falls uncharacteristically silent.

"A robot is not a weapon," he says, after a moment or two. "It can save someone from a sniper's bullet or be used to clear land mines all over the world." That's not to say that he doesn't wake up at night with visions of *Terminator 2* replaying in his mind. "Creating machines to fight wars might indeed create more war … even robot wars," he says. "And I don't want to go down in history as the father of weaponized robots."

In fact, he may go down in history as the first soldier to put tactical mobile robots to the test. In mid-January, four months after his unauthorized, post-retirement mission at the World Trade Center, Blitch was called back into active duty – with orders to assemble a team of robots for the mission. ■ ■ ■