Originally published in March 2004

A New Race of ROBOTS

Around the U.S., engineers are finishing one-year crash projects to create robots able to dash 200 miles through the Mojave Desert in a day, unaided by humans. *Scientific American* tailed the odds-on favorite team for 10 months and found that major innovations in robotics are not enough to win such a contest. Obsession is also required

BY W. WAYT GIBBS

PITTSBURGH, DECEMBER 10, 2003: A cold rain blows sideways through the night into the face of Chris Urmson as he frets over Sandstorm, the robotic vehicle idling next to him on an overgrown lot between two empty steel mills. Urmson checks a tarp protecting the metal cage full of computers and custom electronics that serves as the sensate head of the chimeric robot, which has the body of an old Marine Corps Humvee. His ungloved hands shivering and his body aching from three sleep-deprived days and nights of work in the field, Urmson stares glumly at the machine and weighs his options. None of them are good.

JANUARY 20: Sandstorm grows faster, smarter and more robust almost every day. Yet Whittaker still gives it only 40 percent odds of finishing the race.

W. WAYT GIBBS

The Competitors

MORE THAN 100 TEAMS registered for the Grand Challenge; 86 sent technical applications to DARPA, which approved 45. DARPA officials later culled the field to 25 vehicles, which fall into roughly four categories. No more than 20 will be allowed to race.

Modified All-Terrain Vehicles

Pros: Inexpensive; off-road suspensions are standard; can stop, turn and accelerate quickly; small size provides a margin of error on narrow trails.
Cons: Sensors are low and thus limited in their range of view; high risk of critical damage in a collision; very limited ability to generate electrical power; small fuel tanks; overturn easily.
Teams: ENSCO, Phantasm, Virginia Tech

Modified Sport-Utility Vehicles

Pros: Easily acquired; good ground clearance; large enclosed interior for electronics; powerful engines; high mounting points for sensors.
Cons: Expensive; high rollover risk; complex electrical system; suspension is designed for paved roads rather than trails.
Teams: Arctic Tortoise, Axion Racing, Caltech, Digital Auto Drive, Insight Racing, Navigators, Overbot, Palos Verdes Road Warriors

Dune Buggies

Pros: Very low center of gravity prevents overturning; frame and suspension are customized for desert racing; lightweight, agile and fast.
Cons: Sensors are low and vulnerable to collisions and dust; small wheels; low mass and electrical budgets limit onboard computing.
Teams: AI Motorvator, CyberRider, LoGHIQ, Sciautonics (which is fielding two robots)

Modified Military Vehicles

Pros: Very high ground clearance, stability and crash tolerance; powerful engines and large chassis can easily carry a large payload of electronics and computers; high vantage point for sensors.
Cons: Expensive and hard to obtain; parts are difficult to find; stiff suspension creates problems for sensors; wide turning radius; relatively slow acceleration and braking.
Teams: The Red Team, Terramax

He and his teammates had vowed months ago that by midnight tonight Sandstorm would complete a 150-mile journey on its own. It seemed a reasonable goal at the time: after all, 150 miles on relatively smooth, level ground would be but a baby step toward the 200-mile, high-speed desert crossing that the robot must be ready for on March 13, 2004, if it is to win the U.S. Department of Defense's Grand Challenge race, as well as the $1-million prize and the prestige that accompanies an extraordinary leap in mobile robotics.

But after 20 hours of nonstop debugging, Sandstorm's navigational system is still failing in mystifying ways. Two days ago the machine was driving itself for miles at a time. Last night it crashed through a fence, and today it halts after just a few laps around the test path. The dozen or so team members here are wet, cold and frazzled, hunched over laptops in a makeshift lean-to or hunkered down in a van. The 28-year-old Urmson has hardly seen his wife and two-month-old baby for weeks. Continuing under these wretched conditions seems pointless.

On the other hand, an hour ago he and the rest of the group huddled around William "Red" Whittaker, the leader of the Red Team—and Urmson's Ph.D. adviser at Carnegie Mellon University (CMU)—and acceded to his decision that they would continue fixing and testing through the night and into the day and through the night again, if need be, until Sandstorm completed the 150-mile traverse they had promised. For the umpteenth time, Red repeated the team's motto: "We say what we'll do, and we do what we say." Their reputations, their morale—and for the students, their final-exam grades—are on the line.

But at the moment, Whittaker is not around, so Urmson, as the team's technical director, is in charge. He looks at the rivulets streaming over the tarp, considers how many weeks of work could be undone by one leak shorting the circuits inside, and aborts the test, sending everyone home to their beds.

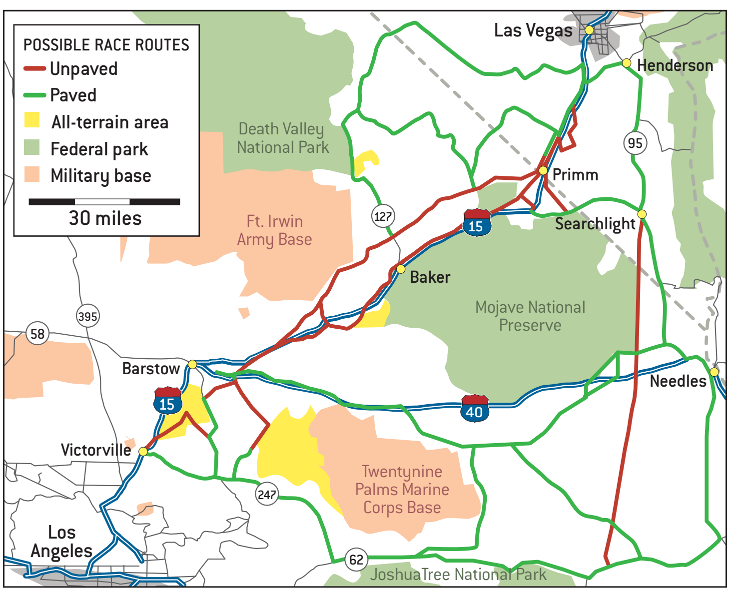
The next day brings hell to pay. Like an angry coach at halftime, Whittaker castigates the team for giving up and for missing other self-imposed goals. "A great deal of what we agreed to do got lost as the team focused monotonically on the 150-mile objective," he rebukes. "The vehicle body didn't get painted; the Web site didn't get updated; the sensor electronics weren't completed. And do we win the race if we don't have better shock isolation than we have now?" Heads shake. "No, we'll lose the race. Is the condition of this shop consistent with who we are?" he asks, waving at the tools and parts scattered over

The Grand Challenge Race

DARPA ANNOUNCED in February 2003 that it was organizing a desert race for self-navigating robotic vehicles to be held on March 13, 2004. The race was named the Grand Challenge because its requirements—cross 200 miles of unfamiliar, rough terrain in 10 hours or less, without any human assistance—fell well beyond the capabilities of any robot yet designed.

THE PRIZE: $1 million to the team whose vehicle completes the course in the shortest time less than 10 hours.

THE RULES: The robotic racers must be fully autonomous; during the race they cannot receive signals of any kind (except a stop command) from humans. The vehicles must stay on the ground and within the boundaries of the course. No robot may intentionally interfere with another. The race will begin with a staggered start; a qualifying event will determine who goes first. If no vehicle wins in 2004, the race will be repeated each year until there is a winner or the funding runs out (after 2007).



THE COURSE: Two hours before the race begins, DARPA officials will give each team a CD-ROM containing a series of GPS coordinates, called waypoints, spaced 150 to 1,000 feet apart. The width of the route between waypoints will also vary: in some sections of the course, racers will have to remain within a 10-foot-wide corridor, whereas in other sections they will be able to roam more freely. Depending on how officials mix and match from various potential routes through the Mojave Desert (*map*), the course may be as short as 150 miles or as long as 210 miles.

RACE OFFICIALS have warned participants to expect sandy trails, narrow underpasses, power line towers and hairpin turns. The Red Team is creating a test course in Pittsburgh that includes all of these hazards.

LUCY READING; SOURCES: MDEP, BLM, SRA/DARPA every flat surface. Eyes avert. He clenches his jaw.

"Yesterday we lost that sense deep inside of what we're all about," Whittaker continues. "What we have just been through was a dress rehearsal of race day. This is exactly what the 13th of March will be like. We're in basic training; this is all about cranking it up a notch. Come March, *we* will be the machine, an impeccable machine."

Whittaker concludes his pep talk and asks for a show of hands of all those willing to devote every minute of the next four days to another grueling attempt to complete a 15-hour, 150-mile autonomous traverse. Fourteen hands shoot up. Sometime between the first team meeting eight months ago and today, each person in the room had passed his own point of no return.

A Grand Challenge Indeed

APRIL 30, 2003: In a conference room at CMU's Robotics Institute, a tall man rises to his feet. He wears the blue blazer and tan chinos of an academic but has the bravado of a heavyweight who used to box for the marines. "Welcome to the first meeting of the Red Team," he booms. "I'm Red Whittaker, director of the Fields Robotics Center, and I am committed to leading this team to victory in Las Vegas next year."

Whittaker attended the conference last February at which officials from the Defense Advanced Research Projects Agency (DARPA) announced their first-ever prize contest, a robot race from Barstow, Calif., to Las Vegas [*see box on preceding page*]. DARPA set up the competition to spur progress toward a vehicle that could enter a battlefield with minimal human supervision. "It could be delivering supplies or taking out wounded. It could also be a tank," says Anthony J. Tether, the agency's director.

A different vision moved Whittaker to be among the first of more than 100 teams that would sign up to enter the race. To him, the principal attractions are the public attention it will bring to robotics and the difficulty of the task, which he often compares to Lindbergh's first transatlantic flight. "The race defies prevailing technology, and many hold that the challenge prize is unwinnable in our time," he wrote in an e-mail on March 13 to potential volunteers and sponsors.

Building an autonomous robot would not be the hard part. With colleagues at the Robotics Institute, Whittaker has created self-driving vehicles that haul boulders, harvest crops, map underground mines, and hunt for meteorites in Antarctica. What makes the Grand Challenge aptly named is its speed—the speed at which the robot must move over rough, unfamiliar terrain and the haste with which it must be built.

"In order to win, Sandstorm will have to average better than 10 meters per second [22 miles per hour]," CMU engineer Scott Thayer points out. That is roughly 10 times the speed of the prototype robots that DARPA has acquired through a four-year, $22-million program to develop unmanned ground vehicles.

"Just getting it to move that fast will be a profoundly challenging problem," Thayer says. "Maintaining those speeds safely for almost 10 hours straight is just mind-boggling." He ventures that "it will take a fundamental innovation to win. And the professional roboticists like me may be the last to come up with a breakthrough like that. After doing this for decades, we tend to think more incrementally. So who knows—one person with a dune buggy may win it."

Blueprint for the Red Team

JUNE 24: "The last time we met, we considered a tricycle with giant wheels seven feet in diameter," Whittaker reports at the team's third meeting. "We also looked at a four-wheel-drive, four-wheel-steered vehicle with a chassis that can change shape. We gave these hard technical looks, but each is too bold a technical step for a yearlong program."

Three months into that year, the team has not yet decided whether to base its robot on a tortoise, such as a military Humvee, or on a hare, such as a professional pickup truck or a low-slung Chenowth combat buggy. Whittaker presents a mathematical analysis of how each vehicle would perform on a course composed mainly of dirt roads and rough trails. "A tough consistent vehicle could go 250 miles in 9.3 hours; a sprinter would take 10.6 hours," he concludes. The choice seems clear, yet it will be September before they will raise the door on the Planetary Robotics Building, where the team has set up shop, and push in a 1986 Hummer M998.

But the group—which now numbers more than 50, thanks to the dozens of CMU graduate and undergraduate students working on the project for credit—has prepared a 58-page technical paper describing how Sandstorm will track its position, plan its route, and detect and avoid hazards in its way. Alex Gutierrez, one of the graduate students at the core of the team, hands out copies to executives from SAIC, Boeing, Caterpillar, Seagate and other corporate partners as they enter the room.

"First we will work for eight months to create the best possible maps of the course terrain," Whittaker explains. "When DARPA hands out the race route, two hours before the race starts, we will use those maps to calculate the optimal route and do a simulated flight though it" [*see box on next page*]. The resulting list of thousands of GPS coordinates will be copied to computers on the robot, giving it "little seeds of corn to aim for every meter or so," Whittaker says. "Sandstorm will just go along like Pac-Man, gobbling up these little virtual dots."

The budget now sums to an astonishing bottom line: $3,539,491. Nearly $2.5 million of that is for personnel expenses that will probably never get paid. The $725,000 for the vehicle itself is not optional, however, and so far only Caterpillar and a local foundation have written checks. But many others are donating valuable equipment and expertise.

Applanix, for example, delivered a $60,000 position-tracking system that not only will allow Sandstorm to know where it is as it bounces along the desert but also will help it to solve one of the toughest problems in mobile robotics: watching where it is going with a steady gaze. "It will know what the world outside looks like through lasers, what it looks like in radar, and what it looks like through a stereo, or two-eyed, camera—provided by our good friends at SAIC," Whittaker declares. Each of these sensors will be mounted on motorized platforms connected to the Applanix system in a tight feedback loop. These gimbals, as engineers call them, will compensate for the motion of the vehicle much like the neck and eye muscles of a human driver.

Many of the competing teams have similar plans. One composed of undergraduates at the California Institute of Technology is forgoing radar and relying heavily on four video cameras mounted to the front of their modified Chevrolet Tahoe. The Red Team's Navtech radar is worth its $47,000 price because "it works through dust, which can blind the other sensors," Whittaker says. For that very reason, Ohio State University's Team Terramax is mounting two radars—plus six cameras and four laser scanners—on the robot it is building from a huge six-wheeled Oshkosh truck.

More sensors are not necessarily better. Each one streams data like a fire hose; too many can choke a robot's computers. As the vehicle jolts and shakes, overlapping scans may confuse more than they inform. And merging sensor data of different types is notoriously tricky. Laser scanners produce "point clouds," radars emit rectangular blips, a stereo camera generates a so-called disparity map. "If you aren't careful," says Jay Gowdy, a CMU scientist on the Red Team, "you can end up combining the weaknesses of each sensor instead of combining their strengths."

Reality Checks In

NOVEMBER 6: Whittaker, Urmson and Philip Koon, one of two engineers that Boeing Phantom Works has embedded with the team, sit down for the weekly teleconference with the team's partners. "We were maybe 50–50 on our goals this week—this is the first time we have really missed the mark," Whittaker announces. The radar was hung up in customs en route from the U.K. After more than 100 hours of work, the mapping group has completed less than 4 percent of the area they aim to cover. And money is getting tight. "At the moment, we're short about $950,000 and burning through eight grand a day," Whittaker reports. He hopes to sell advertising space on the robot's hood

Planning to Win

THE RED TEAM concluded early on that the most feasible way to win the race is to give the Sandstorm robot an extremely detailed and accurate navigational plan to guide it over the race route. The exact course will be held secret until two hours before the starting gun, however. So the team has spent thousands of hours assembling maps, models and aerial imagery of the entire potential race area, which spans 400 times the area shown in this illustration. The engineers overlay, align and hand-correct several distinct views of the terrain.

From the U.S. Geological Survey, the team obtained relatively rough three-dimensional profiles of the land and aerial photography that can distinguish objects as small as one meter. To these they add custom-made road and vegetation maps, then fuse these layers of information into an enormous geographic database several terabytes in size.

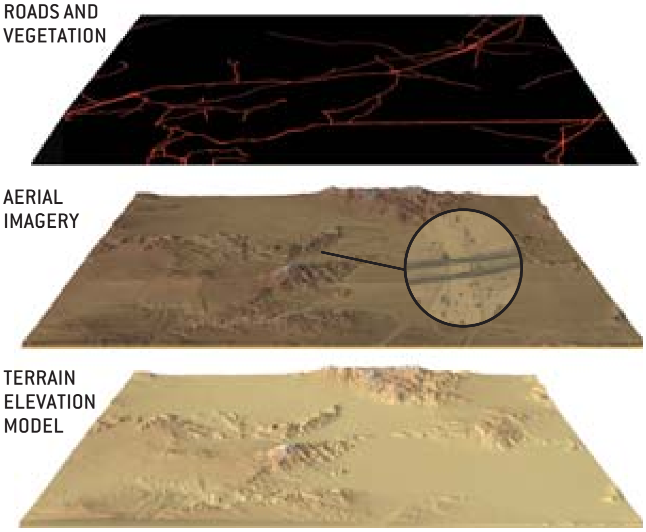
A computer program can use this database to calculate the "cost" for Sandstorm to traverse every square meter in the region. Some areas, such as cliffs or course boundaries, have an infinite cost because they would disable or disqualify the racer. Dry lake beds, in contrast, might have a cost of zero.

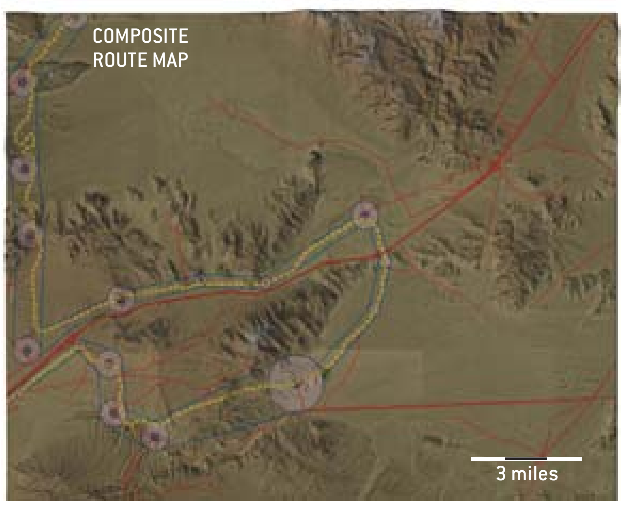
On race day, the actual course data (*simulated below as circles and blue lines*) will be sent through a high-speed link to the Red Team's control center. There a fleet of computers will use the cost map to compute the optimal route. A dozen or more trained volunteers will then divide the route into sections and will tweak the computed plan as needed so that it does not mistakenly send Sandstorm into harm's way. The final navigation instructions (*yellow dots*) will be beamed to the robot shortly before the race begins.

ROADS AND VEGETATION

AERIAL IMAGERY

TERRAIN ELEVATION MODEL





W. WAYT GIBBS; SOURCES: USGS, THE RED TEAM and fin for half a million dollars but has found no buyers.

Two weeks later the team meets to confront other problems. A superprecise optical odometer built to slide on the robot's axle does not fit together properly. "And this is troubling," Whittaker says as he points to a large spike on a graph of how the computer cage—they call it the E-box—bounced around as the vehicle ran over a railroad tie at five miles an hour. "That reads seven g's, which is very bad," he continues. Hard disks will crash and chips may pop from their sockets unless the E-box is isolated from all shocks greater than about three g's. They must figure out a better way to suspend the E-box within the chassis.

"Engineering is always a series of failures to get to success," points out Bryon Smith, one of the few seasoned roboticists on the team. "It takes iteration after iteration to get it right." But iterations take time. The 100 days that Whittaker scheduled for development are almost up, and the team has yet to install and wire all the onboard computers, construct the gimbals, finish the software or mount the sensors.

"This vehicle hasn't rolled so much as a foot under its own control," Whittaker says. "You have promised to get 150 miles on that beast in two weeks. Just so we're clear on the ambition here: DARPA's Spinner vehicle program, based right here at CMU, has a team of pros and a budget of $5 million and is now in its second year. So far the furthest it has driven is 15 miles. Okay, anyone who thinks it is not appropriate for us to go for 150 miles by December 10, raise your hand." No one does. "There it is," he smiles. "We're now heading into that violent and wretched time of birthing this machine and launching it on its maiden voyage."

DECEMBER 1: "There were a bunch of us here all day on Thanksgiving and through the weekend—me, Alex, Philip, Yu [Kato] and several others. But it was worth it," Urmson says. So ends any semblance of normal life as these young engineers are drawn into their leader's constructive obsession. "Around 3 or 4 A.M. Sunday morning, as all the pieces started coming together and getting connected, it felt damn good," Whittaker adds, casting critical looks at those who spent the holiday with their families.

The robot now has several of its sensory organs attached and a rudimentary nervous system working. Smith and Kato have assembled the three-axis gimbal that will aim and steady the stereo camera and long-range laser only to discover "very strange behavior with the fiber-optic gyroscopes" that measure the device's motion, Smith reports. Whittaker listens intently to the details. "The gimbal is an essential device to win the race," he reminds the team. "Its main purpose is to suppress jitter. Right now when we turn it on, it induces jitter." For the next week, Kato will hardly leave the shop as he valiantly attempts to correct through software a fundamental flaw in the gyroscope hardware.

At 7:51 the next evening, after handling well in a piloted test run, Sandstorm is allowed to take its own wheel. It is driving blind, simply following a recorded list of GPS waypoints that trace an oval loop. The computer is doing the steering, but Urmson is on board as a "human kill switch," to hit the emergency stop button if something goes wrong. Four miles and half an hour later programmer Kevin Peterson clicks a button on his laptop, a command travels wirelessly to the robot, and Sandstorm brakes to a halt. "Very well done," Whittaker congratulates, and sends the vehicle back to the shop for another night of modifications.

"From now on we need everybody here 24 hours so that as soon as the vehicle returns from the field, people jump on it and start working," Whittaker says in the morning. "It is exciting to see a robot first spring into action. But the point is to make this kind of driving boring. A 150-mile traverse in the next five days, while taking sensor data: that's the final exam, and it's pass/fail."

DECEMBER 8: The Red Team has set up camp by the empty blast furnaces to watch the robot make its 15-hour nonstop, unguided journey. They record a figure-eight test path, but the machine gets confused at the crossing point; sometimes it goes left and sometimes right. So they go back to the oval loop.

But before the test can begin, a short circuit sends current surging through a wireless "E-stop" receiver that DARPA has provided so that race officials can disable any robot that goes berserk. With that receiver fried, the team has no fail-safe way to force Sandstorm to stop—only a piece of software. Peterson and Martin Stolle, two of the team's software gurus, urge Whittaker not to rely on the software.

Urmson arrives with a servomotor borrowed from a radio-controlled airplane and proceeds to jury-rig a wireless kill switch. But that transmitter also shorts out. "So now we have just Martin's software stop," Whittaker sighs. "Martin, how many hours do you have on your controller?" he asks.

"We've tested it for about half an hour," Martin replies. Moreover, he warns, if the onboard computer fails, "we will lose all control, and the vehicle will just plow ahead until it hits an obstacle larger than a Humvee."

Urmson huddles the team together. "We can go ahead, but we all need to understand and agree that—"

"Everyone understands it, and I'm accountable," Red interrupts. "It's not a question of pros or cons; we're going to do it." The sun has set, and the slush on the track is refreezing. Whittaker insists that two team members stay in the open to keep watch as the robot drives 792 laps around its short test loop.

With a puff of gray smoke, Sandstorm zooms forward. As it rounds the first two turns and enters a straightaway, sparks appear in the undercarriage. It skids to a stop on command, and team members sprint out with a fire extinguisher. The cause is innocuous: someone had forgotten to refill a gas cylinder that keeps the parking brake released, so it was driving with its brake on. They push the vehicle back onto the course, only to find that the batteries have failed.

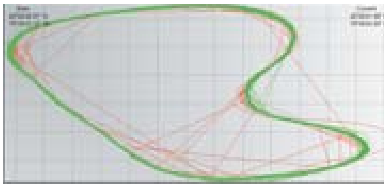
And so it went for the next several days, with one thing after another going wrong. While Smith and Kato managed to conquer the bugs in the gimbal and get one of its three arms working for 15 hours, gremlins bedeviled the rest of the Red Team, sending Sandstorm careening into, and later through, a chain-link fence. In the wee hours of December 13, the robot was just clearing 119 miles when it headed for the hills and had

How Sandstorm Works

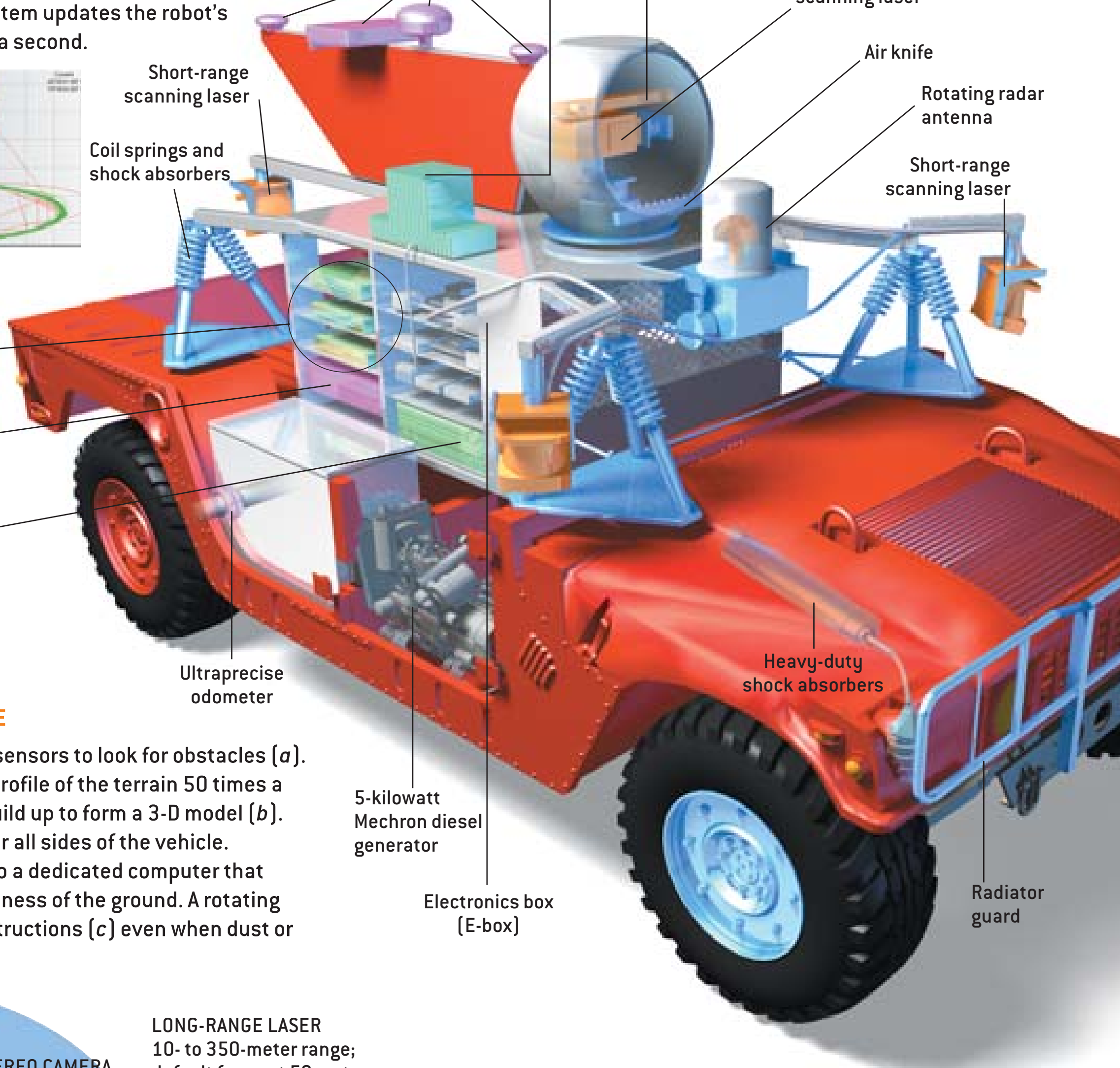
JUST BEFORE THE RACE BEGINS, the Red Team will calculate the best route and send a detailed itinerary (in the form of geographic coordinates for every meter of the course) to the Sandstorm robot. The vehicle will try to follow this virtual trail of breadcrumbs from the starting line to the finish as closely as it can, while detecting and avoiding any unexpected obstacles, such as a disabled racer in the road ahead. To succeed, the robot must solve four challenging problems.

1. TRACKING ITS POSITION

An Applanix navigation computer contains two GPS receivers, three fiber-optic gyroscopes, three silicon accelerometers and an ultraprecise odometer, which it uses to pin down the robot's position to within 50 centimeters and to measure its orientation in space to 0.4 degree. The system updates the robot's sense of where it is 200 times a second.

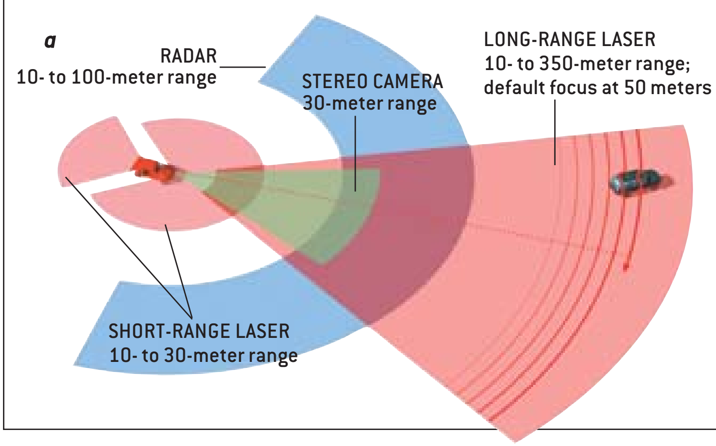


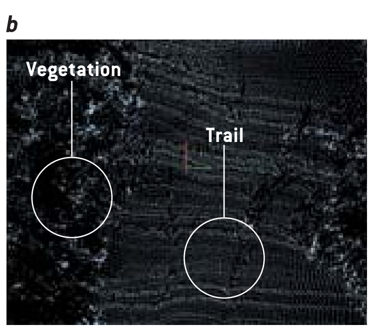
GPS trace of 119-mile test (red lines are sensor glitches)

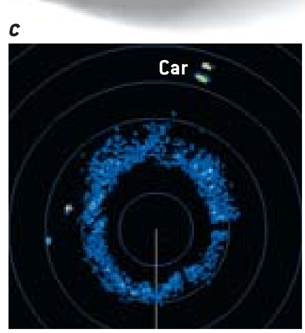


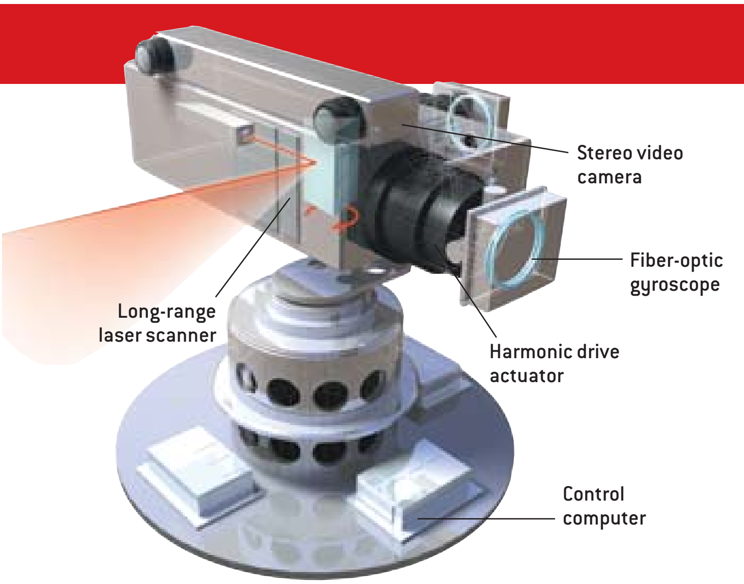
2. PERCEIVING AN OBSTACLE

Sandstorm uses four kinds of sensors to look for obstacles (*a*). A long-range laser traces the profile of the terrain 50 times a second. Successive profiles build up to form a 3-D model (*b*). Shorter-range lasers also cover all sides of the vehicle. A stereo camera sends video to a dedicated computer that estimates the slope and roughness of the ground. A rotating radar antenna will pick up obstructions (*c*) even when dust or glare blinds the other sensors.







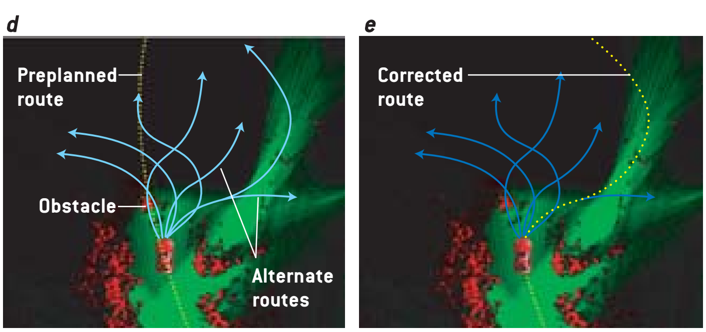


4. ENDURING THE DUST AND BUMPS

Back roads through the Mojave are rough, so the team has equipped the Humvee with racing shocks and springs, a radiator guard and run-flat wheels. To protect the computers, the electronics box is suspended on tripods of spring-reinforced shock absorbers and strapped in place by superstrong bungee cords. A dozen "ruggedized" hard disks inside will operate in redundant pairs. As Sandstorm bounces over a washboard dirt road at 30 miles an hour, it must hold its forward sensors steady. Red Team engineers built a computer-controlled stabilizer, or gimbal (*above*), that both aims and steadies the camera and long-range laser. The gimbal uses three fiber-optic gyroscopes and three precise actuators to measure and compensate for the vehicle's pitch, roll and yaw. The radar is similarly bolted to a one-axis gimbal.

3. REVISING ITS ROUTE

Even the best maps are not up to the minute. So three onboard Xeon computers will use data from each sensor to update the "cost" assigned to each square meter in the area. A paved road carries a cost of zero; a cliff or competing racer warrants an infinite cost. Several times a second, a fourth Itanium2 computer checks whether the "breadcrumb trail" (*d, yellow dots*) passes through high-cost territory (*red areas*). If so, the planner program prices alternative routes (*blue arcs*) and shifts the breadcrumbs to the shortest safe path (*e*).



BRYAN CHRISTIE DESIGN (*illustrations*); SOURCE: THE RED TEAM

to be stopped. They persisted for two more days, through a snowstorm and bitter cold, persisted and failed.

Sprinting to the Starting Line

DECEMBER 21: "We didn't do the 150," Whittaker acknowledges, as the diehards meet to take stock. "But it was a hell of a four days. It was our battle cry, and it was magnificent."

On Christmas Eve a new shock isolation design for the E-box is tested. It works, as do all three arms on the gimbal. Christmas Day brings—what else?—test, fail, rework, repeat.

Within two weeks, as industry partners fly in for the last full team meeting on January 6, the robot is ready for its public unveiling before politicians and television cameras. Behind closed doors, Whittaker acknowledges that "in the last six months we've fallen behind a month. Following GPS waypoints, the vehicle is now rock-solid, to the point where you can turn your back on it." Sandstorm has graduated from a paved lot to an open field, where it now safely drives by itself at more than 30 miles an hour.

But although the machine can see the world, it cannot yet reason enough to avoid obstacles. Even with 10 of the most powerful processors that Intel makes installed in Sandstorm, the computers formulate their plans about a third too slowly.

In February the robot and its creators will head to the desert. "We need to put 10,000 miles of testing on it," Whittaker says. "This fancy stuff could shake apart because it's all prototype. Just inside the E-box there are 5,000-odd components, a failure in any one of which could screw us up. Any team could beat us."

And if the Red Team wins? The best thing about building a new race of robots, Whittaker said one frigid night in December as we watched Sandstorm do its laps beneath a nearly perfect full moon, is not the act of creation. "What's most fun is exploring the space of possibilities you have opened with your invention. I'm thinking about proposing a mission to NASA to launch a lunar rover that could circumnavigate the pole of the moon, searching for ice." Other team members have suggested building a robot to run the Iditarod in Alaska or to serve as an ambulance in Antarctica.

More likely, however, the $1-million prize will go unclaimed this year and the contest will repeat in 2005. "If no one wins this race and we recommit for next year, who's in?" Whittaker asks at the end of the meeting. Up go a roomful of hands. SA

Senior writer W. Wayt Gibbs has been in Pittsburgh covering the progress of the Red Team since March 2003.

MORE TO EXPLORE

The Red Team Web site: **redteamracing.org**

For links to other teams: **www.darpa.mil/grandchallenge/teams.htm**

For more information on the Grand Challenge race: **www.darpa.mil/grandchallenge/**