Embedded.com

Autonomous vehicles to put embedded technology to the test

By Charles J. Murray, Embedded.com
Mar 9 2004 (12:00 PM)
URL: http://www.embedded.com/showArticle.jhtml?articleID=18311516

Ground-based transportation will take a new turn this week, as 20 driverless vehicles, described as "supercomputers on wheels," race across the southern California desert in a million-dollar, winner-take-all competition sponsored by the U.S. Defense Advanced Research Projects Agency.

Darpa's Grand Challenge race, possibly the most daunting test ever for robotic technology, will take the vehicles over sand dunes, through valleys and across rivers at speeds up to 60 mph. Covering a course stretching from Barstow, Calif., to Las Vegas, it will call on the vehicles to traverse almost 250 miles in less than 10 hours, all without human intervention. The competing vehicles - marshaling an army of computing technologies, sensors, motors, satellite-based navigation schemes and by-wire automotive systems - are testbeds for revolutionary systems envisioned for defense, industry, agriculture and, in particular, automotive transportation. "The Mars rover navigates unknown terrain, too - but not like this," said Brad Chen, senior architect for Intel Corp.'s Performance Tools Lab, a corporate sponsor of one of the teams. "The rover has to navigate 88 feet per day, whereas these vehicles go 60 miles per hour."

Competing in the Grand Challenge requires such extraordinary compute power that some entrants are said to pack more than 60 pounds of on-board computers. A tricked-out Hummer from Carnegie-Mellon University, for example, incorporates a four-way Intel Itanium-based parallel-processing system and three dual Xeon processor setups. And a team from SciAutonics LLC (www.sciautonics.com) is using a PowerPC-based vehicle-control computer, three ruggedized laptops and a separate industrial computer, all connected over an Ethernet data bus, to handle the inputs from navigation systems, ultrasound sensors and infrared lasers around the vehicle.

"To make the vehicle completely autonomous, you have to have enough computing power to replace a human," said Reinhold Behringer, president of SciAutonics.

Why do so? "A truly autonomous vehicle could revolutionize land transportation," said William (Red) Whittaker, Fredkin research professor of robotics at Carnegie Mellon and team leader for the university's Red Team vehicle (www.redteamracing.org). "If you add up all the applications of this technology in energy, agriculture and defense, the sum of it doesn't even approach its potential in the automotive market."

The race, scheduled for Saturday, March 13, will be held on an as-yet-unpublished course between Barstow and Vegas. About two hours before it begins, Darpa officials will give participants approximately 1,000 global-positioning-system "way points" that will define the course. To traverse it, participating vehicles will augment GPS navigation with other technologies.

Tech package

For its entry, an all-terrain vehicle from ATV Corp. that has been transformed for the race, SciAutonics opted for a StarFire GPS from NavCom Technology Inc., together with an inertial-measurement unit and a magnetometer (digital compass). Engineers said the combination of technologies is needed because GPS, even with its ability to provide positioning accuracies within 10 cm, operates no faster than 5 Hz " insufficient for on-the-fly positioning of a vehicle traveling up to 60 mph.

The inertial-measurement unit (IMU), commonly used in aerospace systems, aids the navigation effort by providing the vehicle's acceleration and rotation values. When the vehicle makes a slight turn, the IMU measures the change in the vehicle's heading angle and "decides" whether the vehicle is still on its desired path. "It allows us to fill in the data gaps between the GPS signals," said Behringer of SciAutonics.

The company's vehicle uses the magnetometer to provide heading information while the vehicle is standing still, since GPS works only when the vehicle is moving. Engineers said, however, that processing GPS data is only a small part of each vehicle's overall task. Because much of the race takes place off road, the vehicles must also be capable of reading the terrain, navigating around rocks and trees, and even recognizing steep drop-offs.

"One scenario for these vehicles is that they will drive right off a cliff," said Charles Reinholtz, alumni distinguished professor of mechanical engineering at Virginia Tech University (www.me.vt.edu/grandchallenge), whose design team of 30 students and nine advisers named its vehicle Cliff with that very possibility in mind. "Perceiving a drop-off is very difficult for a computer because [a drop-off], unlike a tree or rock, is a 'negative obstacle.' "

Even so-called positive obstacles represent a challenge, Reinholtz said. Computer vision systems, which will be employed by most entrants, are established technologies but nevertheless have difficulty identifying objects and deciding whether or not to go around them, especially at 60 mph.

"A person can look at a tree and know it's a tree," Reinholtz said. "But what makes a tree a tree? How do you get a computer to recognize a tree?"

Virginia Tech's squad is trying to do just that by using seven computers from National Instruments on board a four-wheel-drive utility cart. Four major sensing systems - an Eaton Vorad radar unit, Sick Optic laser range finders, differential GPS and a visible-light camera - are connected to dedicated cFP-2010 compact field point (CFP) computers from National Instruments. Virginia Tech's vehicle, called Cliff, incorporates radar, laser range finders, differential GPS and a visible-light camera.

"The CFP units can send a signal back to the other computers that essentially says, 'The coast is clear,' " Reinholtz said. "If the terrain is extremely rocky, it knows to go around the rocks. If there's a river, it avoids that."

The CFP units send their data to three PXI-8176 controllers, which hold a geographic database consisting of topographical descriptions (for example, slope grades, elevations and types of land cover). Ultimately, those machines make the navigation decisions, with input from the sensors.

The compilation of sensors and GPS equipment exacts an extraordinary computing toll on the vehicles, engineers said. Stereo-vision systems require the processing of up to 60 frames/second, for example, and scanned images are used to create a terrain model. Terrain models are then combined with physical models of the vehicle and course to enable the vehicle to follow the correct path. Processing all that data is a big task, race participants said.

That's why Carnegie Mellon's team incorporates a four-way Itanium-based computing system in tandem with three dual-Xeon processor systems on board its Hummer, which Intel's Chen called a supercomputer on wheels. Moreover, Chen said, sophisticated navigation and obstacle-avoidance software was written for the race and then combined with Intel compilers, Intel Vtune performance analyzer software and third-party GPS software.

"We like to say that there are many ways to lose this race," said Chen, who received his PhD in computer science from Carnegie Mellon in 1994. "But the way to win it is with software."

While navigation presents a formidable task for engineers, participants must find substitutes for a driver's hands and feet as well as a driver's eyes. They're accomplishing that with by-wire systems that incorporate motors at the steering wheel, brake pedal, accelerator and gear shift.

SciAutonics, for example, employs three servo motors, rated at 27 ft-lb apiece, to work the brake, accelerator and gear shift. It also uses a larger servo motor, in conjunction with a drive belt, to turn the steering wheel. When the vehicle is moving, information from the optical sensors passes through a ruggedized computer from Kontron America. The data is then reduced to a simple command signal, which in turn is sent to a central vehicle-control computer. The computer runs an Integrity operating system from Green Hills Software Inc. that generates a command to turn, brake or accelerate.

Plotting a path

"We take all the data, run it through algorithms that measure the heading and steering, plot a path to the next way point and send the command to the motor that turns the steering wheel," said Behringer of SciAutonics. While some on-board computers employ Windows 2000 operating systems, he said, the vehicle-control computer requires the response time of a true real-time OS.

Engineers said last week that the technology could be a boon for a variety of applications, inside and outside defense. Agricultural machinery, for example, now traverses more than a billion miles a year in the United States alone, they said, and many of those miles could be more effectively navigated by autonomous equipment. Similarly, carmakers are already employing autonomous features, such as adaptive cruise control, collision avoidance and lane-keeping, that could act as a foundation for work toward even greater autonomous control using the robotics employed in the Grand Challenge vehicles.

"We've thought about collision avoidance, but how about predictive passing?" asked Whittaker of Carnegie Mellon. "These systems could not only help you get around the vehicle you're passing; they could help you to decide whether to pass, as well.

"This goes beyond anything we've seen up to now. It gives machines the capacity to anticipate and predict " and that's a very big deal," he said.