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NOVEMBER 2005
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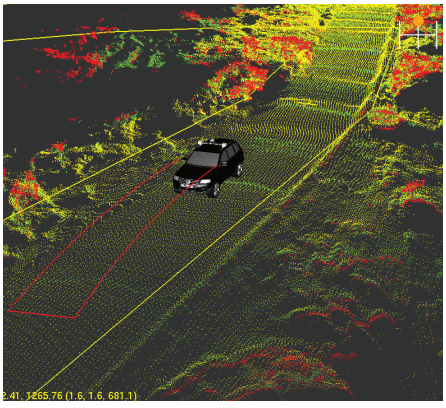

Photos courtesy of Stanford Racing Team.

Robot on the Run

Stanford's Stanley Takes DARPA Grand Challenge Prize

Stanley, the robotic Volkswagen Touareg from Stanford University, won the 2005 Grand Challenge mounted by the Defense Advanced Research Project Agency (DARPA). With no one at the wheel, Stanley covered the 131-mile Mojave Desert course in 6 hours, 53 minutes, 8 seconds, at an average speed of 19.1 miles per hour — good enough for $2 million.

Stanley incorporates measurements from a NovAtel Propak LB GPS receiver with OmniStar HP differential corrections, an Inertial Sciences Inc. ISIS inertial measurement unit, a Novatel Beeline GPS compass, and wheel odometry from the Touareg's CAN bus.

In motion, Stanley perceives the environment through five laser rangefinders, a monocular video camera, and radar for long-range sight. The sensors acquire data at rates of 10 to 100 Hz. Map and pose information are incorporated at 10 Hz. Processing takes place on six Pentium M motherboards in a rugged rack mount unit.

Despite this impressive list of hardware, "We treated this as a software problem," said Mike Montemerlo of the Stanford racing team. "The first year [of the Challenge], people did a lot of hardware application. But I basically saw it, the critical part, taking place in software."

Montemerlo wrote an unscented Kalman Filter (UKF) to integrate the measurements and generate a 6-degrees-of-freedom (DOF) pose of the vehicle. The output of the UKF and the laser data serve as inputs to Stanley's "mapper," which outputs an obstacle map to "the planner," which plans a safe trajectory and outputs it to "the controller," which sends throttle, brake, and steering commands to the Touareg, enabling it to avoid obstacle collisions obstacles in real time while advancing along the route.

"The UKF is a version of the extended Kalman filter (EKF) that handles nonlinear systems more accurately than the EKF," said Montemerlo. "It's also easier to implement correctly. When you have these multidimensional nonlinear systems, computing derivatives can be long and complicated. In my own experience, I frequently got it wrong. The unscented filter computes derivatives numerically. You put in your motion model and your measurement model of all your sensors, and it takes care of computing the derivative automatically."

Overtaken at the Pass. Stanley did not grab the lead from his nearest competitor until the most difficult obstacle, Beer Bottle Pass, seven miles from the finish line. Extremely steep, with a mountain on one side of the road and a 100-foot drop on the other cliff, Beer Bottle Pass

represented “a catastrophic failure mode,” recalled Montemerlo. “From a GPS perspective, that was probably the worst environment because you don’t have a complete view of the sky, and very little tolerance, maybe 10 feet, in your zone.”

Advancing at 10 miles per hour, Stanley grazed the edge of the road a couple of times, causing onlookers to hold their breath. But he completed the climb and roared down to the finish in Primm, Nevada, where team members, journalists, and officials had followed the race by video feed and 3D mapping projectors, in huge tents erected in a parking lot surrounded by casinos and hotels.

Two vehicles outfitted and trained by Carnegie-Mellon University’s Red Team finished just minutes behind, when all official pauses were reconciled and computed. The veteran Sandstorm came in at 7:04:50 and race rookie H1ghlander at 7:14:00. Both vehicles used Applanix POS LV, Trimble Zephyr antennas and AG 252 GPS receivers, and OmniStar correction data. The Gray Team’s KAT-5 (7:30:16) used an RT3000 inertial/GPS unit from Oxford Technical Solutions, which incorporated a NovAtel receiver and OmniStar corrections. Oshkosh Truck’s 16-ton TerraMax, with Trimble AgDGPS and OmniStar, finished the next morning.

CLARIFICATION

In an August story, “Melee in the Mojave,” we identified another GPS receiver and differential service for Stanley. Sometime during the summer, the Stanford team made a change to those listed here.