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RACE FOR THE PRIZE

BEATING THE CHALLENGES OF ROBOT RACING

The 2005 DARPA Challenge tested developments in autonomous vehicle research, especially in the realm of inertial/GPS navigation. Combining GPS integrated inertial navigation systems with real-time terrain modeling puts engineers on the threshold of introducing robot vehicles into everyday life

It's been said that there are no winners in desert racing, only survivors. The 2005 DARPA (Defense Advanced Research Projects Agency) Grand Challenge is just such a race with one interesting spin: there are no drivers walking away at the finish line. The challenge was to create and successfully race a driverless vehicle across a desert range at Primm, Nevada, with natural and man-made obstacles in place designed to block GPS signals, break wheel struts, and to send designers home frustrated. The first team to finish in less than 10 hours claims a US$2 million prize. Conceived in 2001, the first DARPA Grand Challenge, held in March 2004, had a US$1 million prize and

THE WINNERS (MAIN PHOTO) AND H1GHLANDER (RIGHT)

no winner. The furthest distance traveled: a mere 7.6 miles. In 2005, the purse doubled and so did the number of team entries.

This year's group of challengers collectively demonstrated the latest concepts in vision, radar, laser, and GPS/inertial navigation sensors, as well as steering actuation, drive-by-wire technology, and software to translate data into forward motion. Some 195 teams applied to join the 2005 race and almost all technical and academic backgrounds could be found: high schools and universities, automotive manufacturers, software designers, robotics hobbyists, and even members of the entertainment industry. After a thorough examination, 43 team entries were selected to participate in the qualification semifinals. From this, only 23 teams would earn the right to compete for the grand prize.

Of all the teams present throughout the competition, Team Red from Carnegie Mellon University (CMU) appeared to be in the spotlight more than any other. After traveling the furthest in 2004, Red Team was determined to complete the course first and take home all the glory. This time they arrived with two vehicle entries. "Sandstorm" was a 1986 model 998 HMMWV and the veteran DARPA distance record holder from last year's competition. CMU's new contender, "H1ghlander", was a 1999 H1 HUMMER and the pole position winner after the qualification round. Clearly fan favorites, both trucks were very conspicuous; less so for their size and crimson body paint than for the impressive array of rooftop sensors.

Long before this race began, and despite all that was learned from 2004's trials, it wasn't initially obvious what would be different come the rematch. Then Dr Anthony Tether, the creator of the DARPA Grand Challenge, delivered a keynote speech in which he reiterated the importance of route sensing to contestants and technologists. It suddenly became clear… DARPA was determined to challenge all sensors and all vehicles – especially those with a high reliance on GPS navigation. Before the conference ended, sensor shopping lists had grown.

Around the same time as vehicle designs were being drafted and redesigned at CMU, a meeting between Red Team and Applanix over the capabilities of POS LV technology quickly developed into a strong partnership. The reason for Red Team's interest in inertial GPS technology was quite simple. "Knowing its exact position, accurately and in real time, is obviously important to an autonomous vehicle," explains Louis Nastro, director of land products at Applanix. "However, knowing its orientation is absolutely essential. Consider that GPS signals are received at a rate of 1Hz. During any period of GPS obstruction, even if absent for only a single second, a fast moving vehicle traveling at, say, 20m/sec can quickly veer off course by relying solely on positioning. GPS needs to be bridged when obstructions degrade or completely obscure signals." As the industry leader in inertial geospatial solutions, Applanix was invited to demonstrate how an inertial measurement unit (IMU) coupled with a GPS processor produced far faster and much more accurate position and orientation measurements than either unit can generate alone.

Remarkably sensitive devices, today's advanced inertial measurement systems can record even the slightest change in motion through a triad of accelerometers and gyroscopes, supplying accurate data in six axes. Given a starting reference point, all movements can be measured accurately and used for making navigational adjustments over prolonged periods.

Adding time-matched data for distance, speed, direction, and other navigational inputs greatly improves overall system's accuracy. Even with a single GPS signal, such a navigation system can produce sub-meter results and even sub-decimeter results with Real Time Kinematic (RTK) GPS. Naturally, supplementing a vehicle's GPS and IMU position data using a standard car odometer or speedometer would not be satisfactory. A successful design must incorporate a specialized Distance Measuring Instrument (DMI) in order to provide highly accurate travel distance data when a GPS signal is unavailable.


SANDSTORM

This significantly reduces IMU error growth over prolonged GPS outages.

ROBOT STANCE

Positioning solutions for advanced robot vehicles (other than the most basic systems that rely solely on straight GPS) span three basic types. The first, and most rudimentary, is a dead reckoning module (DRM), which utilizes accelerometers and gyroscopes to estimate position when GPS is unavailable. While this is a cost-effective solution to bridging GPS gaps, the types of sensors used (usually MEMS based) start to drift substantially within a few meters traveled.

Furthermore, the orientation data produced by such modules is not typically of navigation quality. The second type is a loosely coupled GPS/INS positioning solution, which provides protection against GPS dropouts and orientation information, but the GPS data is either accepted or rejected in the real time positioning estimate. The Applanix POS LV solution is an example of the third type of system approach, referred to as tightly coupled inertial GPS processing. Raw GPS observables are incorporated into the positioning solution based on their quality, and then those signals are weighted and combined with the IMU and DMI data. This produces the most accurate and robust position estimate. The advantages of such a system are further illustrated when utilizing RTK GPS where RTK positioning can be reacquired very quickly during GPS outages. In contrast, if one were using standalone RTK, even if there are less than three or four satellites in view, the system would lose RTK and reacquisition could take minutes..

Because the DARPA Grand Challenge is a race and not just a technology test bed, data processing is arguably more important than sensor system redundancy. Passing and processing data at a very high data rate helps vehicle routing adjustments to be performed far more safely and effectively, especially at high speeds in constantly changing terrain. A system must be able to compare all sensor data fast enough to plot an optimal course for a vehicle maintaining a minimum average speed of 17.5mph (175 miles maximum course length, 10 hour time limit). While certain sensors may be relied upon more under specific conditions than others, a program that includes a measure of "navigation by jury" flexibility can help a robot vehicle stay on course by recognizing false or absent readings, data outliers, or blinded sensors.

Carnegie Mellon University engineers immediately recognized the value of having data from the GPS, IMU and DMI blended together in real time and began working to include the POS LV system on both Red Team vehicles. Practically plug-and-play, it wasn't long before the Applanix hardware and software was working in full cooperation with all other navigational sensors onboard both vehicles. The advantages to the Red Team would soon become apparent.

If Red Team's two vehicles were to successfully overcome the surprises waiting for them in the desert, system cooperation was essential. Sensors responsible for scanning ahead and 'driving' the vehicle needed to work hand-in-hand with inertial GPS navigation equipment and, at critical times, possibly depend on it entirely. Similarly, inertial GPS can't adjust for unexpected road conditions, nor can it negotiate the best path between a handful of waypoints along a cliff, across varying terrain, or maneuver around large obstacles. Scanning lasers, cameras, and radar technology were relied upon to produce a composite model of the terrain ahead, while POS LV technology generated accurate positioning data along the course in addition to relying on its inertial navigation components at critical times. Designed to fully share navigation duties with forward looking radar and laser optic scanners, a potential race champion is born, built with enough redundancy to achieve the mission should a problem occur.

When entering long dark tunnels designed to completely block all GPS signals, the POS LV inertial navigation system took over and cooperated perfectly with laser and radar sensors until a GPS signal could be reacquired. Compact, light weight, and fully integrated, the completed system worked "hot-on" according to Team Red members, generating pinpoint vehicle movements under the most difficult of conditions.

The race results now rest in the history books. Of the 23 vehicles to qualify on race day, only five completed the course, and only four of those did so within the time limit. After leading for most of the race, both of CMU's vehicle entries finished back-to-back over the finish line with times of 7:04:50 and 7:17:00, finishing moments behind the Stanford Racing Team who posted a time of 6:53:58. Even more astonishing, it was discovered after the race that the lead CMU vehicle H1ghlander had experienced significant performance problems during the majority of the course, and before the treacherous mountain pass where one mistake would have resulted in a 200 foot drop off the course.

Overcoming a mechanical handicap that would have put most other teams out of the race, H1ghlander set a blistering pace in the most difficult area of the course, a testament to the quality and reliability of the position and orientation system working within a redundant sensor system design. Fourth to finish was the Gray Team using a 2005 Ford Escape SUV hybrid design. The only other vehicle to complete the challenge was Team TerraMax's Oshkosh Truck, which finished after the 10 hour time limit had passed.

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NO POINTS AT STAKE

All the teams were part of something much larger than a race… something that brought the future one dusty step closer. Competitive gains from critical technologies such as inertial navigation systems with GPS technology prove how close we are to resolving major development hurdles, including location accuracy requirements for pinpoint vehicle navigation. But no matter what the strategy, no matter what the design, all teams that entered the 2005 DARPA Grand Challenge have ultimately contributed greatly to automated vehicle development. With great endings come new beginnings. ■