2007 Urban Grand Challenge

by Richard Murray

The Lee Center was one of the funders of Caltech's entry in the 2007 Urban Grand Challenge, an international autonomous vehicle competition sponsored by DARPA. Team Caltech was formed in February of 2003 with the goal of designing a vehicle that could compete in the 2004 DARPA Grand Challenge. Our 2004 vehicle, Bob, completed the qualification course and traveled approximately 1.3 miles of the 142-mile 2004 course. In 2004-05, Team Caltech developed a new vehicle, Alice, to participate in the 2005 DARPA Grand Challenge. Alice utilized a highly networked control system architecture to provide high performance, autonomous driving in unknown environments. The system completed several runs in the National Qualifying Event, but encountered a combination of sensing and control issues in the Grand Challenge Event that led to a critical failure after traversing approximately 8 miles.

As part of the 2007 Urban Challenge, Team Caltech developed new technology for Alice in three key areas:

1. mission and contingency management for autonomous systems

2. distributed sensor fusion, mapping and situational awareness

3. optimization-based guidance, navigation and control.

Support from the Lee Center was used to developed some of this technology, primarily through support for undergraduate research projects (SURFs) and the purchase of system hardware.

For the 2007 Urban Challenge, we built on the architecture that was deployed by Caltech in the 2005 race, but provided significant extensions and additions that allowed operation in the more complicated (and uncertain) urban driving environment. Our primary approach in the desert competition was to construct an elevation map of the terrain surrounding the vehicle and then convert this map into a cost function that could be used to plan a high-speed path through the environment. A supervisory controller provided contingency management by identifying selected situations (such as loss of GPS or lack of forward progress) and implementing tactics to overcome these situations.

For the urban environment, several new challenges had to be addressed. These included the determination of road location based on lane and road features; avoidance of static and moving obstacles; and successful navigation of intersections. We chose a deliberative planning architecture, in which a representation of the environment was built-up through sensor data and motion planning was done using this representation. A significant issue was the need to reason about traffic situations in which the vehicle interacts with other vehicles

Alice

Top row (L to R): unknown (DARPA), Sam Pfister, Noel duToit, Tony Tether (former DARPA director), Cisco Zabala, Tony Fender, Mohamed Aly, Humberto Pereira, Andrew Howard (JPL), Richard Murray, Laura Lindzey, Sandie Fender. Bottom row (L to R): Nok Wongpiromsarn, Jeremy Ma, Josh Oreman, Christian Looman.

or has inconsistent data about the local environment or traffic state.

The following technical accomplishments were achieved as part of this project:

1. A highly distributed, information-rich sensory system was developed that allowed real-time processing of large amounts of raw data to obtain information required for driving in urban environments. The distributed nature of our system allowed easy integration of new sensors, but required sensor fusion in both time and space across a distributed set of processes.

2. A hieararchical planner was developed for driving in urban environments that allowed complex interactions with other vehicles, including following, passing and queuing operations. A rail-based planner was used to allow rapid evaluation of maneuvers and choice of paths that optimized competing objectives while also insuring safe operation in the presence of other vehicles and static obstacles.

3. A canonical software structure was developed for use in the planning stack to insure that contingencies could be handled and that the vehicle would continue to make forward progress towards its goals. The combination of a directive/response mechanism for intermodule communication and fault-handling algorithms provide a rich set of behaviors in complex driving situations.

The features of our system were demonstrated in over 300 miles of testing performed in the months before the race, including the first known interaction between two autonomous vehicles (with MIT, in joint testing at the El Toro Marine Corps Air Station)

A number of shortfalls in our approach led to our vehicle being disqualified for the final race:

1. Inconsistencies in the methods by which obstacles were handled led to incorrect behavior in situations with tight obstacles.

2. Inadequate testing of low-level feature extraction of stop-lines created problems with the corresponding fusion into the existing map.

3. Adjustments needed for handling intersections and obstacles proved difficult to modify and test in the qualification event.

Despite these limitations in our design, Alice was able to perform well on 2 out of the 3 test areas at the National Qualifying Event, demonstrating the ability to handle a variety of complex traffic situations. Most important, a new generation of researchers was able to participate in the design, implementation and testing of one of the handful of completely autonomous vehicles that have been developed. L E E

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Read more at: http://www.cds.caltech.edu/~murray