Technical Paper
Team Mojavaton
Car # 1
DARPA Grand Challenge 2005

Team Members

Karl Castleton
Mike Claeys
Dan Councilman
Dave Crawford
Jim Crittenden – team leader
Crag Frazier
Paul Hallmann
David Lafitte
Warren MacEvoy
Phil Miller
Mark Moore
Alan Peck – assistant team leader
John Trotter

Corporate Sponsors

Alpine Powder Coating	Automation Direct	Automotive Customizers
Barney Brothers Off Road	Big “O” Tires	CoorsTek
Copley Controls	Crossbow	DVT Sensors
Earth LCD	Entivity	Foxhaven Video
Fuoco Motors	Galil Controls	General Technics
Genesis Engineered Solutions	Kearfott Navigation	Navcom
Optech	Platinum Signs	PNI
SICK	Tee Time USA	Visual Expressions

Contact information
Jim Crittenden
970-241-0097
rehoboth75@aol.com

Submitted: August 28, 2005

Abstract: Team Mojavaton's vehicle in the DARPA Grand Challenge 2005 is a 2001 Nissan Xterra. It is equipped with three GPS systems, an inertial navigation system, and 9 terrain sensors. The system strategy is simple: drive straight to the next waypoint unless one or more of the sensors indicates that it is inadvisable to do so. In that event, a new route is planned and followed that avoids the unsafe area. Virtual waypoints are computed on-the-fly to supplement the DARPA waypoints. Waypoints in curves are fitted to a spline to better define the course. The car is capable of driving many roads using only sensor input and without any GPS waypoint guidance.

1-Vehicle Description

Our vehicle is a commercially available 2001 Nissan Xterra SUV. Standard equipment includes a 3.3 liter V-6 gasoline powered engine, automatic transmission, anti-lock brakes, and air conditioning. We added a 3" suspension lift kit, 32" off-road tires, undercarriage steel skid plates, a front bull bar bumper, 4 driving lights, a cat-back exhaust system, a cold air intake system. The rational for this choice was that we didn't want to spend time designing and building a vehicle. We wanted to spend time on the sensory and navigation systems, so we bought a commercial vehicle that was as close as possible to what was needed and modified it in the ways described above.

2 – Autonomous Operations

Processing:

Our Xterra carries one computer. It is a General Technics industrial rack mounted PC running Windows XP Professional. It uses dual 2.8 GHz Xeon™ microprocessors and has a RAID hard disk drive. Communication between the computer and the various system components are done with an Ethernet network. An Automation Direct programmable logic controller is used to provide an interface to the analog and discrete devices. The upper level, supervisory software utilizes Entivity's Studio – a Windows based program designed for custom machine control. Modules that provide data analysis, navigation, and path planning are written in C++ and interface with Entivity through Modbus TPC/IP.

Localization:

We use three GPS systems – a Navcom Starfire™ 2050G with its subscription correction signal, a Garmin GPSMap 76CS, and the embedded GPS in the Kearfott inertial navigation system. Navcom data is updated at 10 Hz. The Garmin updates at 0.5 Hz. A MIL-NAV inertial navigation system from Kearfott is computing position at 50 Hz and becomes the primary source of position information when the Navcom reports its data as invalid. It also serves as an error check for the Navcom data.

No external map data is used in our system. We use the waypoints as rough estimates of where the car should be and use our sensors to detect whatever conditions occur along the course without any prior knowledge of the area.

Sensing:

9 sensors have been added to detect internal and external conditions.

A. One Crossbow 3 axis accelerometer measures G forces in the X, Y and Z direction. This is mounted inside the car.
B. Two SICK LMS-291 2 dimensional laser range finders. One is mounted on the front bumper. The other is mounted on the roof. Both are configured for 1 degree x 180 degree field of view and their effective range is approximately 30 meters.
C. Two DVT 542C color cameras. These are mounted inside the car on the dashboard looking forward through the windshield. They are programmed to detect the edges of the road ahead. Their field of view is 30 degrees and effective range is approximately 40 meters. These cameras have automatic exposure adjustment to compensate for changes in lighting conditions.
D. One stereo camera. This is also mounted inside the car on the dashboard and looking forward through the windshield. Its field of view is 45 degrees and its range is approximately 35 meters. This also has automatic exposure adjustment.
E. One Optech ILRIS-3D three dimensional laser range finder is mounted on the roof. Its field of view is 40 degrees x 40 degrees and its range is approximately 500 meters.
F. One PNI TCM2 digital compass. This reports heading, tilt and roll of the vehicle.

G. One Kearfott MIL-NAV inertial navigation unit. This unit provides tilt, roll, and acceleration, in addition to latitude/longitude position information.

Sensors B through E look for road features and other obstacles. They report their data to either Entivity or to a C++ module. The main supervisory program runs at 20 Hz and considers the input from these sensors on every scan. When it determines that it is not safe or advisable to drive straight towards the next waypoint, a path planning algorithm generates several alternative paths and evaluates them to find the best choice. Then new waypoints are generated along this new path and the steering algorithm follows these new waypoints. Once the sensors report that the path is clear, the program resumes following the original waypoints.

The terrain sensors B through E are integrated by generating a terrain map that uses the rear differential of the vehicle as the datum. Position of obstacles are mapped and then remembered via a time decay algorithm. Obstacles are mapped according to their latitude/longitude position.

Sensing of the internal state of the vehicle comes from sensors A and F. Sensor A is used by the velocity control program to detect the condition of traveling too fast on a rough road.

Vehicle control:

The drive-by-wire system is composed of 6 devices:

A. A servo motor and a zero backlash gearbox turns the steering wheel. An optical encoder on the servo motor reports the exact position of the steering wheel.
B. A pneumatic cylinder operates the brake. An electronic pressure regulator controls the amount of force that is applied to the brake pedal.
C. A servo motor is connected to the engine throttle via the cruise control cable. An optical encoder reports the exact position of the throttle.
D. A dual pneumatic cylinder shifts the transmission between neutral, drive, and reverse. A small pneumatic cylinder pushes the button on the transmission shifter that allows it to go into reverse.

E. A joystick is mounted on the console and allows a person to steer the car while the steering servo system is engaged. The brake and the gas pedal can be operated normally at all times, even when the drive-by-wire system is fully engaged.

F. A high speed counter monitors the engine RPM. This serves two functions: to prevent excessive engine RPM and to detect an engine stall. If the engine stalls, it can be restarted by the computer.

The path planning algorithm attempts to maintain the vehicle's front differential directly above the proper path at all times. The rear differential is allowed to "float" and merely follows the front. This algorithm computes "virtual waypoints" between the DARPA supplied waypoints. On long straight portions of road, it adds these virtual waypoints for local guidance when the DARPA waypoint may be over a mile away. In curves, the algorithm fits a spline to the given waypoints and adds additional virtual waypoints to smooth the path. All positional computing is done in spherical coordinates. Once the path has been chosen, the proper position for the steering wheel is determined and this information is passed to the servo controller for the steering servo motor. The program recomputes its desired path, its position on the path, and the proper steering wheel position 20 times per second. The DARPA lateral boundaries along the course are marked as hard boundaries on the ground map.

The velocity algorithm computes a desired speed 20 times a second based on input from many factors including DARPA speed limit, self imposed vehicle speed limit, roughness of terrain, straightness of the course just ahead, tilt of the car, sensor reporting of obstacles and roughness, and the DARPA speed limit at the waypoint that is approaching (so that if the speed limit drops, we are at that speed by the time we reach the waypoint). A closed loop PID system adjusts the throttle and brake to maintain the velocity at the desired speed within a range of +/- 2 mph. This closed loop system guarantees that no matter how low the desired speed, the throttle will continue to increase until either that speed is reached, or the engine is at its maximum RPM. When it fails to advance forward, it will slow the engine, and shift into reverse. It will then reverse steer back through the previous waypoints until it regains the course.

Braking is handled with the same closed loop system that controls the throttle. If the vehicle is ordered to stop, it will begin to apply air pressure to the brake cylinder. The system monitors the velocity and will increase the air pressure if the vehicle is not responding as desired. Compressed air is supplied by a compressor that automatically maintains 80 to 100 psig. An auxiliary pressure sensor monitors the air pressure in the storage tank and will trigger an emergency stop if the pressure is approaching the minimum required pressure for safe operation.

The vehicle can be driven at any time by a human using the gas and brake pedal. The autonomous systems do not disable either of these devices. The steering wheel is connected to the servo motor via a timing belt and cannot be turned by hand while connected. If the computer is running, a push of one button will enable the console joystick which enables a person to steer the car. If the computer is not running, a wrench is used to loosen and remove the steering timing belt, at which time the car can be steered normally. A quick release pin must be removed to shift the transmission.

System tests:

Our Xterra has driven over 500 miles in fully autonomous mode. Some of this was in paved parking lots, some was over unpaved desert roads. We are fortunate in our location (Grand Junction, Colorado) to be surrounded by hundreds of miles of public, unpaved roads through BLM desert. To date, the only component that has failed as the result of this testing was the vibration mounts for the lower SICK LIDAR. These were replaced with a more robust design. We also noted some screws and bolts that loosened. We said in our application video (back in February) that we had tested the Xterra to 35 mph and that we hoped to test to 65 mph by the end of July. We have recently allowed the Xterra to drive at 75 mph for 2 miles in fully autonomous mode and it did so successfully.

The process of designing and assembling the drive-by-wire systems, the communication systems, and the computer systems was rather straightforward. Our 13 person team is experienced with custom machine design, electronics, machining, and machine vision systems. There were a number of design attempts that turned out to be dead ends and had to be abandoned (using the car's existing cruise control actuator, for example), but in the end, we are very happy with our car and very proud of the workmanship in it.

There does not appear to be any one sensor that can "do it all". Each sensor has its strengths and its weaknesses. The 2D LIDAR is fast and accurate, but has an extremely limited field of view and not a very long range. It's like looking at the world through a slit. The color cameras are good at road finding when the 'road' and the 'not-road' are different colors. On some desert roads, this is not the case. Stereo vision was the most difficult data analysis challenge, but in the end, has become a very useful sensor. Using a unique and proprietary algorithm, we are able to use the fast, 30 frames per second, update rate from the stereo vision camera and detect most obstacles easily. The 3D LIDAR is rock solid on measurement accuracy and has a very long effective range. Although not designed for this mobile application (it's normal use is to be mounted on a tripod and spend 30 minutes accurately surveying an object of interest), we have been able to reprogram the unit to be very useful in this mission. We originally thought that it would only be able to perform in a "stop and stare" mode. That is, when the other sensors were too confused, we would stop for a minute, turn on the 3D LIDAR, and collect a highly accurate point cloud mapping of the terrain. We are now able to use the 3D LIDAR while in motion. In the cases of all four terrain sensors, we have been successful at developing proprietary data analysis and, in some cases, proprietary communication systems that have enabled us to get more out of these devices than we initially thought was possible.

We began this project by reading the technical reports from last year's contestants and gleaned what we could from their experiences. We would like to express our appreciation to those "First Generation" teams for their pioneering work in this field. To the extent that we "Second Generation" teams do well, it will be because we stand on the shoulders of those who were there first. We are especially grateful to those fellow Grand Challenge competitors who have been willing to share their knowledge directly and on the DARPA GC discussion forum. Ivar Schoenmeyr of Team CyberRider in particular has distinguished himself for his spirit of cooperation and willingness to share information.

The support that we received from our more than two dozen sponsors was astounding. When we explained the Grand Challenge and its goal, the vast majority of people that we approached said “What can I do to help?”. In the end, most of the cost of the project was covered by corporate donations of equipment. We are very grateful to our corporate sponsors, our entry would not have been possible without them. And finally, we would like to express our gratitude to DARPA for sponsoring the Grand Challenge. They have said that it is “outside the box thinking” that they are trying to foster with this event, and the truth is that they themselves have set the standard for outside the box thinking by creating the Grand Challenge. We hope that we will be worthy of their efforts.