DARPA GRAND CHALLENEGE 2005

TEAM: TEAM AION

DATE: 8/09/2005

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Abstract

Our strategy, overall, consists of several phases: First we built a modular foundation drive-by-wire system with redundant EStop and Disable. Second, we integrated our navigation and waypoint handling into a module called DriveByGPS which motivates a waypoint file. Third, we created a virtual bumper that assures that course modifications will always be safe. Fourth, we created an object navigation module to take heading instructions and condition them to the optimal route. We believe that with our blend of processing power, software strategy, contingency planning, and redundant design will enable AION to reach the finish line within the specified time limit.

Introduction

We've designed the AION system for redundancy, stability, performance, and modularity. With a six cylinder Jeep Cherokee modified for off-road performance and ground clearance, power, stability, and cooling, we've outperformed our expectations in our foundation vehicle repeatedly in the field. Though the system is modular by design and exchanging base vehicles would take us less than a week, we have no expectation of that need.

With the inherent redundancy built into AION each subsystem is independently guarded against failure. For instance, a failure of 120VAC power within the vehicle would activate automatic shifting into neutral, full brake, and leveling of steering at the motor controller level within one second. If the network failed, a software EStop would shift into neutral, overriding brake and acceleration. With risk analysis and redundancy planning we can guarantee that in the event of any failure, AION will stop.

However, we see the Grand Challenge ultimately as a contest of software. Our software strategy overall consists of five phases: First we built a modular foundation drive-by-wire system complete with redundant EStop and Disable and all of the base functionality required by the Grand Challenge rules. Second, we integrated our sensor-independent navigation and waypoint handling into a module called DriveByGPS which motivates a waypoint file into target speeds and target steering which the drive-by-wire system actuates. Third, we created a virtual bumper that assures that course modifications will always be safe. Fourth, we created an object navigation module to take DriveByGPS's instructions and modify them so that the virtual bumper would never need to stop the vehicle while still executing the instruction as best possible. Lastly, we will test in the field with a target of approximately 3000 miles of online test time, recording every anomalous feature with which AION has difficulty. We will then take that data back to the laboratory until the exception can be cured (based on priority of likelihood of occurrence).

Is it our belief that our blend of processing power, software strategy, contingency planning, and redundant design will enable AION to reach the finish line within the specified 10 hour time limit.

People

Core Team

Josh Bernheim, Team Leader
Qualifications: Studied Physics, Computer Science & Engineering, and Philosophy independently and at UCSC, as well as 5 years as President of Dataczar Automation, the chief sponsor and motivator of Team AION's participation in the DARPA Grand Challenge. Josh has extensive interest in robotics and is pleased to be a part of this exciting event.

Jared Coates, Program Manager
Qualifications: Studied Management Science at UCSD and has been COO of Dataczar Automation for 3 years. As Program Manager Mr. Coates is responsible for budgeting, scheduling, and coordination of team events. With particular focus on discipline Jared assures that the project gets done on time within budget.

Scott Reid, Chief Programmer

Qualifications: Studied Computer Science at CSUSM. Our design process includes steps for defining requirements, writing a specific design, executing the design, testing integration, and maintenance. Scott has been active in all of these roles and is very pleased to be a part of this historic event.

Ray Neff Jr., Mechanic

Qualifications: With 10 years of experience creating and modifying vehicles for off-road racing, as well as being an off-road racer himself, Ray has been a terrific asset for welding, building, modifying, and allowing us to do basically anything to the AION hardware. He's also turned our straight six into a steady and reliable workhorse machine capable of powering all of the internal subsystems of the AION vehicle and proved a valuable consultant on off-road racing.

Daniel O'Steen, Electrical

Qualifications: As a hobby engineer and mechanic, Daniel has learned to wire anything from 120VAC to sensitive robotics and sensors through direct experience. A fast learning and a great researcher, Daniel is personally responsible for many of the high-performance-for-cost subsystems we've included in the vehicle, including the Dead Reckoning VNU, Bumblebee stereo vision system, and Eaton Radar.

Honorary Team Members

Daireus Mann, Programmer

Isaiah Coates, Mechanic

Mary Vo, Secretary

Ray Neff Sr., Fabrication

Michelle Bernheim, Volunteer

Brian Bernheim, Volunteer

1. Vehicle Description

1.1. Describe the vehicle. If it is based on a commercially available platform, provide the year, make, and model. If it uses a custom-built chassis or body, describe the major characteristics. If appropriate, please provide a rationale for the choice of this vehicle for the DGC.

1994 Jeep Cherokee

1.2. Describe any unique vehicle drive-train or suspension modifications made for the DGC including fuel-cells or other unique power sources.

Increased capacity gas tank (30 Gal.); Procomp Suspension lift with off-road tires

2. Autonomous Operations

2.1. *Processing*

2.1.1. Describe the computing systems (hardware and software) including processor selection, complexity considerations, software implementation and anticipated reliability.

Drive – Single 64 bit AMD Athlon processor

> Handles all standard drive operation: Controls accelerator, steering, and brake during normal operation (Control can override the brake via hardware). Also collects data from vision and control, as well as hardwired sonar, radar, and VNU data.

Vision – Dual 64 bit AMD Opteron processors

> Vision subsystem, collects data from stereo cameras at 30 fps and distills it into safe speed and obstacle recognition data. The data arrays are transmitted over the network in timestamped UDP packets to Drive. Data is used as it is available by Drive.

Control – Single 32 bit AMD Sempron processor

> EStop controller: Controls shifter and brake override; Takes over if Drive goes down.

There are four full scale computer on board rack mounted with shock absorbers.

- The CONTROL system supervises operation and implements software responses to RUN/PAUSE/DISABLE regardless of malfunction of any of the other three machines. This machine runs on a AMD Sepron 1400 with 512GB RAM and a 36GB HD.
- The DRIVE system coordinates vehicle behavior during normal RUN operation. This machine runs on an AMD 64 2800+ with 1GB RAM and a 36GB HD.
- The VISION system handles vision preprocessing for the roof stereovision system. This machine runs dual 1.6 GHz AMD Opteron 64 processors with 1GB RAM and a 36GB HD.

2.1.2. Provide a functional block diagram of the processing architecture that describes how the sensing, navigation and actuation are coupled to the processing element(s) to enable autonomous operation. Show the network architecture and discuss the challenges faced in realization of the system.

Sensory data is collected in the “Mindspace” structure of the DRIVE system’s software. The software is constructed with interchangeable modules that can be exchanged for different purposes. In the main loop, the software regularly polls a series of “DriveBy” class modules. The DriveByCushion module is polled first which uses sensory data to prevent exceeding a speed that would result in a crash in the current direction. It provides its results by conditioning the output of the DriveByNavigation module which performs the more complex obstacle navigation based on input from DriveByGPS. Primary challenges to implementation was in assuring stability.

2.1.3. Describe unique methods employed in the development process, including model driven design or other methods used.

By making the software modular we allowed ourselves to test on various smaller robots with simpler electronic drive systems to work out the bugs in modules before using them on AION.

2.2. *Localization*

2.2.1. Explain the GPS system used and any inertial navigation systems employed during GPS outages (as in tunnels). Include a discussion of component errors and their effect on system performance.

All localization data is processed through a Kalman filter on a VNU™ from Pt Research. A AgGPS Omnistart VBS subscription GPS feeds this unit. This unit includes accelerometers for pitch, roll, azimuth change, absolute acceleration in x, y, and z, a compass, and a hard-connection to the output shaft speed of the tire rotation. The system is accurate to 2% of distance traveled without GPS data.

2.2.2. If map data was an integral part of the vehicles navigation system, describe the requirements for this data and the way in which it was used.

No map data is used in the vehicle navigation system.

2.3. *Sensing*

2.3.1. Describe the location and mounting of the sensors mounted on the vehicle. Include a discussion of sensor range and field of view. Discuss any unique methods used to compensate for conditions such as vibration, light level, rain, or dust.

A total of 16 forward sonar modules and 8 aft sonar modules detect obstacles reliably to 6m. Mudguards and bumpers protect the transducers of these units. Two stereovision cameras are employed for midrange obstacle detection and lane assurance within 50m. Both cameras are mounted in aluminum hoods to protect the camera from heat and debris. The protective hoods also incorporate tinted windscreens that help reduce glare and over exposure of the CMOS imaging sensors. A SICK ladar scanner is shock mounted above the radar and sonar array on the front of the vehicle. It detects obstacles as well as terrain stability up to 20m. And an Eaton Vorad radar unit reliably detects discrete obstacles up to 80m out. All sensory data (except radar) is redundant so that a failure in any particular sensor is automatically compensated for by other sensors of similar range.

2.3.2. Discuss the overall sensing architecture, including any fusion algorithms or other means employed to build models of the external environment.

Once conditioned and validated, all sensory data is brought together in relative coordinates as relevant to heading into the Mindspace structure.

2.3.3. Describe the internal sensing system and architecture used to sense the vehicle state.

Conditions that can be detected are: engine off, steering position, brake position, shift position, accelerator position,

2.3.4. Describe the sensing-to-actuation system used for waypoint following, path finding, obstacle detection, and collision avoidance. Include a discussion of vehicle models in terms of braking, turning, and control of the accelerator.

DriveByGPS provides heading and speed data relevant to waypoint acquisition to the DriveByNavigation module. Once within a certain radius of a GPS point, the waypoint is considered satisfied. GPS dictates the desired heading relative to the current heading and the desired maximum speed. These signals are conditioned using first an intelligent module operating on Mindspace to calculate the best path to achieve the target heading given the environment, and then by the safety layer which limits speed and fast turning according to safety. Speed is handled by a target speed variable which translates desired speed into actual speed through actuation on the brake and accelerator. Acceleration is used reactively to slow target acquisition on the upside. Acceleration is released immediately when target speed is below current speed.

2.4. *Vehicle Control*

2.4.1. Describe the methods employed for common autonomous operation contingencies such as missed-waypoint, vehicle-stuck, vehicle-outside-lateral-boundary-offset, or obstacle-detected- in-path.

If a waypoint is actually missed, AION will return to acquire it. The waypoint must be achievable within the lane boundaries in order to succeed. If the vehicle is stuck with an object in front of it, it will automatically back up (avoiding rear obstacles) for a time, and then reattempt the course. If the vehicle is stuck, in that no distance is gained for a certain amount of wheel revolutions, it will also attempt to back up for a time. While in the lateral boundary offset as well as outside, the vehicle will weight available headings according to the lateral boundary offset as well as with other weights. If an obstacle is detected in the path of travel within 20m (the vehicle will have slowed by the time this proximity is reached) the course will be altered the minimum amount necessary to clear the object in the best possible detected direction according to obstruction. This will be continuously reevaluated as the obstacle is traversed until the lane of travel is free and a more direct route to the waypoint can be achieved.

2.4.2. Describe the methods used for maneuvers such as braking, starting on a hill, or making a sharp turn without leaving the route boundaries.

Braking is released slowly and is adaptive based on the frequency of the output shaft speed. If braking is released on a hill, it will adjust reactively according to acceleration until the target speed is reached. The jeep will also remain in 4 wheel drive low at all times. This will allow the vehicle to resist rolling backwards even when the brakes are released on a fairly steep hill. A sharp turn would occur based on a weighted calculation that dictated it was the best course. The route boundary would be considered in the calculation and would not be violated.

2.4.3. Describe the method for integration of navigation information and sensing information.

A three step process is used: first GPS data and the waypoint file is turned into relative heading and speed signals. These signals are then processed using the available environment and rules data according to weights. The best selection is then passed to a safety system with final limitation of speed and steering based on the environment detected.

2.4.4. Discuss the control of the vehicle when it is not in autonomous mode.

A joystick can be used to control the vehicle by substituting GPS-guided heading and speed signals with manual ones.

2.5. *System Tests*

2.5.1. Describe the testing strategy to ensure vehicle readiness for DGC, including a discussion of component reliability, and any efforts made to simulate the DGC environment.

Regular testing in similar terrain to the race will ensure readiness. We have tested failure conditions of many individual components to assure that redundant fail safes are functional. Our testing regiment includes three days a week of testing at off-road parks including Corral Canyon, Ocotillo Wells, as well as 4WD trails in the Borrego desert.

2.5.2. Discuss test results and key challenges discovered.

Reliable sensor data, proper calibration of navigation and sensors, and power availability have been key challenges.