DARPA Grand Challenge 2005
Technical Paper for BJB Engineering, Team D112

Prepared for: DARPA

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Abstract

The BJB Engineering team has put together an autonomous vehicle using mostly off-the-shelf components. The program that runs the vehicle does not require any more computing power than can be found in a modest desktop computer. The way that the information is processed is what sets us apart from the competition.

Team Introduction

BJB Engineering is the team name for a small group of individuals whose goal is to do something significant. The DARPA Grand Challenge presents that opportunity. Led by Brian Beal, an engineer whose regular job involves the design and development of custom automated machinery. He has experience with mechanical and electrical design, as well as programming motion control and machine vision systems.

Dennis Shaffer is a Journeyman Electrician who has experience as a maintenance electrician in a manufacturing plant. Dennis initially received his technical training from the Navy, where he was a helicopter technician.

Tom Shea is a Human Resources Manager by trade, so he has used his people skills to help find sponsors and get publicity for the team.

Many other individuals and companies have made this project possible.

Vehicle Description

The vehicle, named “Quadrivium”, is based on a 1992 Isuzu Trooper. This vehicle was chosen because it was already owned by Brian and he decided that it would be capable of running the Grand Challenge course. Modifications to the vehicle, not related to autonomous operation, include the following:

1. Replacing the stock alternator with a 150-amp unit.
2. Installing larger off-road tires.
3. Moving the battery to the passenger compartment.
4. Installing an engine driven on-board-air compressor system.
5. Modifying the fuel system to accept an auxiliary fuel cell.

Drive-By-Wire

Modifications related to autonomous operation are many. The most essential is the installation of a "drive-by-wire" system. A servomotor actuates the steering. A sprocket has been installed on the steering wheel hub, and a chain runs to the servomotor, which is mounted directly below the steering column. The servo is controlled from a Yaskawa LegendMC motion controller. The LegendMC is a networked controller and receives its commands over the vehicle LAN system. A resolver is used to initially home the steering wheel to a center position, then position is tracked using the motor mounted encoder.

The throttle is actuated by a servo driven ballscrew assembly. A cable connects the ballscrew drive to the cruise control brackets above the throttle pedal. The servo is controlled by a Yaskawa LegendMC. The whole ballscrew/motor assembly rides on a slide table that is actuated by a pneumatic cylinder. The cylinder has two positions: engaged or disengaged. The pneumatic cylinder is controlled by a solenoid that is tied into the emergency stop system. The cylinder is normally held in the disengaged position by a return spring. Unless the cylinder is engaged, the throttle cannot be actuated by the ballscrew system. If an E-Stop is initiated, the throttle is immediately disengaged. The E-Stop cannot be reset unless the throttle is in the idle position.

The brake is actuated by a pneumatic cylinder. A spring normally applies braking force to hold the vehicle in place, or bring the vehicle to a stop, even if power assist is not available. A solenoid is tied into the E-Stop system to overcome the spring force during normal operation. A Parker pneumatic electronic pressure regulator is used to apply the proper braking force.

The automatic transmission can be shifted using a LINAK linear actuator that is connected to the console shift lever. Potentiometer feedback is used to determine gearshift position.

Sensors

Primary navigation utilizes information received from a Thales DG16 GPS unit. The DG16 receives differential corrections from a stand-alone Omnistar VBS receiver, Coast Guard beacons, and the WAAS system. The DG16 will use the best differential solution that is available. The GPS antenna is permanently mounted to the roof of the vehicle, while the Omnistar antenna is magnetically mounted. A Garmin GPS18 is also used as a back up to the Thales unit. Position update rate with the DG16 is approximately 8Hz. Autonomous guidance by GPS is not absolute. Other sensors can override the GPS position commands if it is deemed necessary.

There are a number of sensors on the vehicle to interpret the physical environment around the vehicle. Three of the main obstacle detection sensors are mounted to a rotary table at the front of the vehicle (Figure 1). A SICK LMS291-S14 is mounted on its side, and scans in a vertical plane to detect objects up to a distance of approximately 30 meters. A Doppler radar detects objects up to a distance of approximately 300 meters, and an ultrasonic sensor detects objects up to a distance of about 10 meters. All three of these sensors sweep from side to side to scan the area in front of the vehicle. There are also ultrasonic sensors that look a short distance in front of, and to the side, of the vehicle. There is one of these on each side of the front bumper, and they are pointed downward to sense any vertical walls or drop-offs next to the vehicle. An accelerometer is used to help determine the type of terrain that the vehicle is traversing, and a camera is used for detecting road edges and making steering adjustments as necessary. The camera is located in the passenger compartment, and the windshield washer can be activated to clean the windshield if needed. Air is fed to the front of other sensors to help keep them free of dust.

An aircraft type electrically driven directional gyro is used to provide heading information if the GPS signal is unavailable. Vehicle speed (and distance moved) can be determined with the vehicle's rear wheel anti-lock brake sensor. This sensor puts out a sine wave whose frequency is directly proportional to vehicle speed.

Figure 1

Power

Most of the power to run the systems is derived from the main engine. Electrical power is derived from the 12V alternator/battery system. A sine wave inverter is used to get 120 VAC power. A sine wave gas engine driven generator is also used, but only for back-up purposes. If the inverter fails, then the power source is switched to the generator. All systems power goes through an Uninterruptible Power Supply (UPS), so power source switchovers do not affect systems operations. The engine driven air compressor supplies air for the pneumatic system, but an electrically driven compressor is plugged into the generator for back-up purposes.

Processing

The main processing is done on an industrial computer using a 2.4 GHz Pentium4 running Windows 2000. The computer is loaded with only the software that is required of the vehicle, and has been extremely reliable. The computer is mounted in the main electrical enclosure, which is shock mounted. The hard drive of the computer is also mounted on shock and vibration isolators. The navigation program and all communication drivers to the SICK laser, Thales DG16, Garmin GPS and LegendMCs are original. The program polls the GPS unit for current position. This position is compared to the RDDF course, and corrections are made to keep the vehicle on, or near, the course line. If an obstacle is detected, the vehicle will slow down, and the obstacle(s) position will be determined. If an obstacle is in the intended path of the vehicle, then a course will be plotted around the obstacle. Commands to the servo controllers are sent over the Ethernet network. Communications with the GPS units use standard RS-232 ports. Communications with the SICK laser use a special 500k-baud RS-422 communications card. All other sensors and controls are connected to the computer through data acquisition cards. Figure 2 shows the general sensor and information flow.

Both steering and speed control utilize PID control, and the PID parameters change based on different conditions. The decision-making algorithms for navigation are proprietary, but they change based on speed, road conditions, and available sensor information.

Switching between manual and autonomous operation is very easy. The brake actuator cylinder rod end is attached to the brake pedal by pushing it onto a ball type connector and installing a pin. The gearshift actuator is attached by installing two clevis pins and locking clips. Reverse the above steps to convert back to manual control. At that point the vehicle can be driven by a person, and is completely street-legal.

Testing

Testing has taken place at various sites in Northeast Ohio, and at the NUSE2 JOUSTER site in Virginia. Testing has taken place on pavement, gravel roads, dirt roads, and open fields. A practice session is scheduled for late September at the Yuma Proving Ground in Arizona.

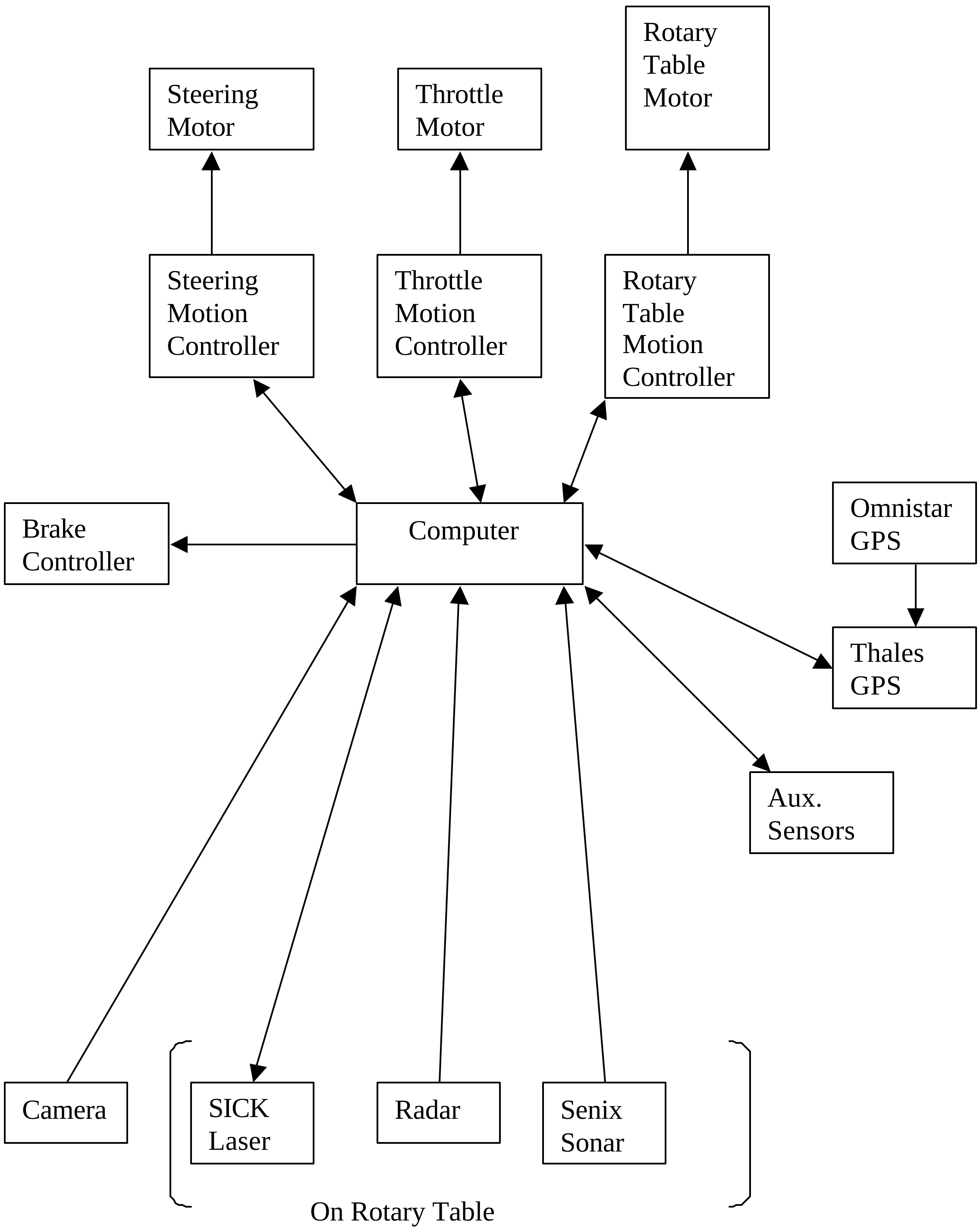
Rotary Table Motor
Steering Motor
Throttle Motor
Steering Motion Controller
Throttle Motion Controller
Rotary Table Motion Controller
Brake Controller
Computer
Omnistar GPS
Thales GPS
Aux. Sensors
Camera
SICK Laser
Radar
Senix Sonar
On Rotary Table

Figure 2