Technical Paper
DARPA Grand Challenge

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Abstract

An autonomous vehicle race through the desert such as the DARPA Grand Challenge presents tremendous technical challenges that push the limit of existing individual technologies, as well as their synthesis into an integrated system. The challenges can be broken down into the following distinct components: goal identification, map assessment and planning to define a path to the goal, real time sensing of the environment to avoid obstacles, selection of the optimal route, and transmission of commands to mechanically move the vehicle. Separately, each of these components has been solved by existing technology. Axion, LLC intends to merge these various solutions into an autonomous racing platform leveraging speed, modularity, and reliability.

1. System Description

a. Mobility

1. Describe the means of ground contact. Include a diagram showing the size and geometry of any wheels, tracks, legs, and/or other suspension components.

The Axion, LLC Challenge Vehicle (AR Challenge Vehicle) platform is a four door 1994 Jeep Grand Cherokee Limited 4x4. It is a standard four-wheel-drive production vehicle (see Figures 1) with enhancements for off-road activities. The AR Challenge Vehicle will contact the ground with four (4) mud terrain tires with a heavy duty inner tube filled with standard tire sealant for puncture fighting. The tires are B.F. Goodrich Mud/Terrain T/A® tires (stock # 417-972) with the following specifications:

Tire Size	Sidewall	Rim Width Range (Inches)	Section Width on Measuring Rim Width	Overall Diameter	Tread Depth (in/32nds)	Revs/Mile at 45 mph	Max Load Single (lbs@psi)
35x12.50R15/C	**RWL**	**8.5 – 11.0**	**12.5 on 10.0**	**34.8**	**21.0**	**598.0**	**2535@35**

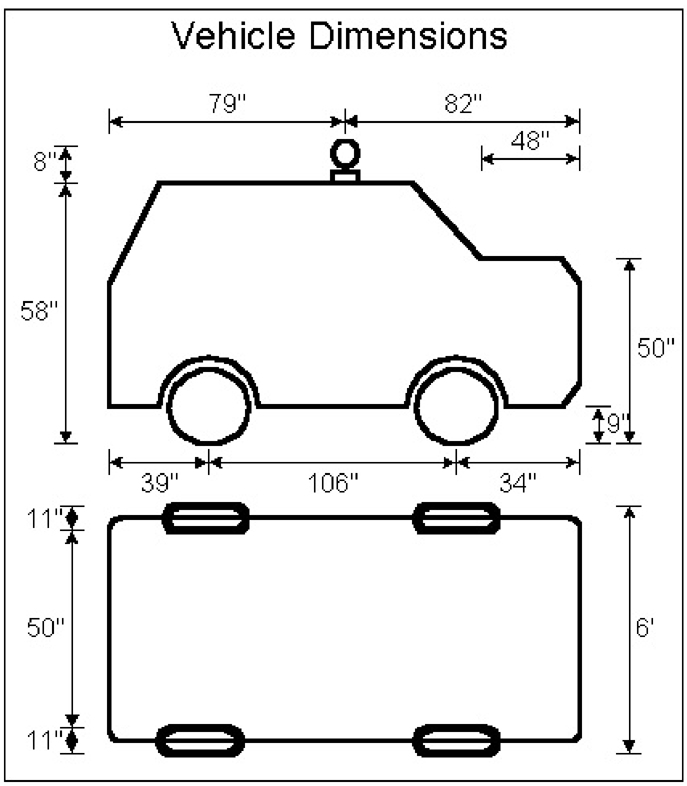

Figure 1: AR Challenge Vehicle

2. Describe the method of Challenge Vehicle locomotion, including steering and braking.

The system is available through Electronic Mobility Controls (EMC), LLC.

The AR Challenge Vehicle's locomotion can be reduced to a two commands: a steering direction, and an acceleration value. The autonomous control system makes its decision and outputs these two values to a National Instruments (NI) Compact Field Point system. The Compact Field Point has a backplane, to which an analog output device is connected. An analog signal is generated for the steering, and another signal is generated for the acceleration. These signals are directed to the AMC Steering Motor Controller and EMC Electric Gas Brake (EGB) units described below. An acceleration signal of zero immediately brakes the vehicle.

3. Describe the means of actuation of all applicable components.

The steering wheel is actuated by means of a DC electric servo motor system consisting of the following components: one DC motor connected to the steering wheel, with a gearbox, one potentiometer steering feedback system connected to the steering motor, one AMC Servo Steering Motor Controller, part #25A8K-ANP. Its important to note the steering wheel can be disengaged from the motor, allowing for manual operation of the steering system. The analog signal sent from the National Instruments goes directly to the AMC Servo Motor Controller, which directs the steering servo motor to the desired position. The servo motor gearing turns the steering wheel in the desired direction.

The Electronic Mobility Controls (EMC) Electric Gas Brake (EGB-IIF) unit is a single servo motor with an arm that travels 270 degrees, that is set up to apply pressure on the factory brake pedal in a travel position from 8 o'clock to 3 o'clock, where 3 o'clock is full brake. Swinging from 3 o'clock to 8 o'clock will bring you to a position of no pressure on the brake and idle on the vehicle motor. Continuing to swing up to 12 o'clock, the same mechanism pulls a cable, which in turn pulls the throttle of the vehicle. This system is commercial off-the-shelf, installed according to manufacturer's specifications. The EGB is controlled by an analog signal from the National Instruments.

The shifting is controlled by means of a linear actuator. The linear actuator provides analog positional feedback information. The AR Challenge Vehicle will utilize park, reverse, neutral, and drive, depending on the circumstances. The linear actuator is controlled by a signal from the National Instruments.

b. Power

1. What is the source of Challenge Vehicle power?

The AR Challenge Vehicle will feature a manufacturer-standard internal combustion engine burning unleaded gasoline, and a bank of four (4) 12V heavy-duty automotive batteries.

Two (2) independent alternators operating redundantly will charge the batteries. A portion of the battery reserve will provide electrical power to the AR Challenge Vehicle. The remaining portion of the battery reserve will in turn power a Zantrex Prosine 2.0 inverter, which will provide clean 120V, 60Hz AC to the computational portion of the AR Challenge Vehicle.

2. Approximately how much maximum peak power (expressed in Watts) does the Challenge Vehicle consume?

The Axion, LLC Challenge Vehicle will consume a maximum 6,000 Watts of electrical power.

3. What type and how much fuel will be carried by the Challenge Vehicle?

The fuel tank for the AR Challenge Vehicle will contain 24 gallons of unleaded gasoline.

c. Processing

1. What kind of computing systems (hardware) does the Challenge Vehicle employ? Describe the number, type, and primary function of each.

The Challenge Vehicle will utilize five (5) shock-mounted Pentium class servers and one (1) National Instruments Compact Field Point system. Four of the five servers are motherboard-based 19" rack-mounted computers, 2 server-unit (2U) form-factor in height. The fifth server is a Dell Optiplex, standard desktop PC. The list below itemizes the servers and describes their respective functions, which are also displayed in Figure 2.

Computer Type	Purpose	Serial #	Location
Dell 2650	Linux system to make Arbitration decisions, interface to LADAR, GPS	F25HG21 (Linux1)	Rear rack
Dell 2650	Linux system to process map database and real time local map creation	5BCK941 (Linux3)	Rear rack
Dell 2650	Windows system to interface to the 3 Bumblebee cameras	F4N7N31 (Windows1)	Rear rack
Dell 2650	Windows system to interface to the FLIR camera and RADAR	CSHH421 (Windows3)	Rear rack
Dell Optiplex	Windows system to provide the user interface and interface to color camera	3BRQ431 (AxionOptiplex)	Side of Rear rack
National Instruments (NI) Compact Field Point	Real time controller to actuate steering, gas, and brake	777317-2020	Between rear seats

National Instruments Compact Field Point system: This system will house one real-time embedded system. The system will run the AR Challenge Vehicle by reading the direction and acceleration decisions, then provide motor servo encoder output to the steering and gas/brake motors. This system will also control the warning lights, siren, and estop mechanism. The system is also responsible for packaging and sending the data received into the standard message format of the system.

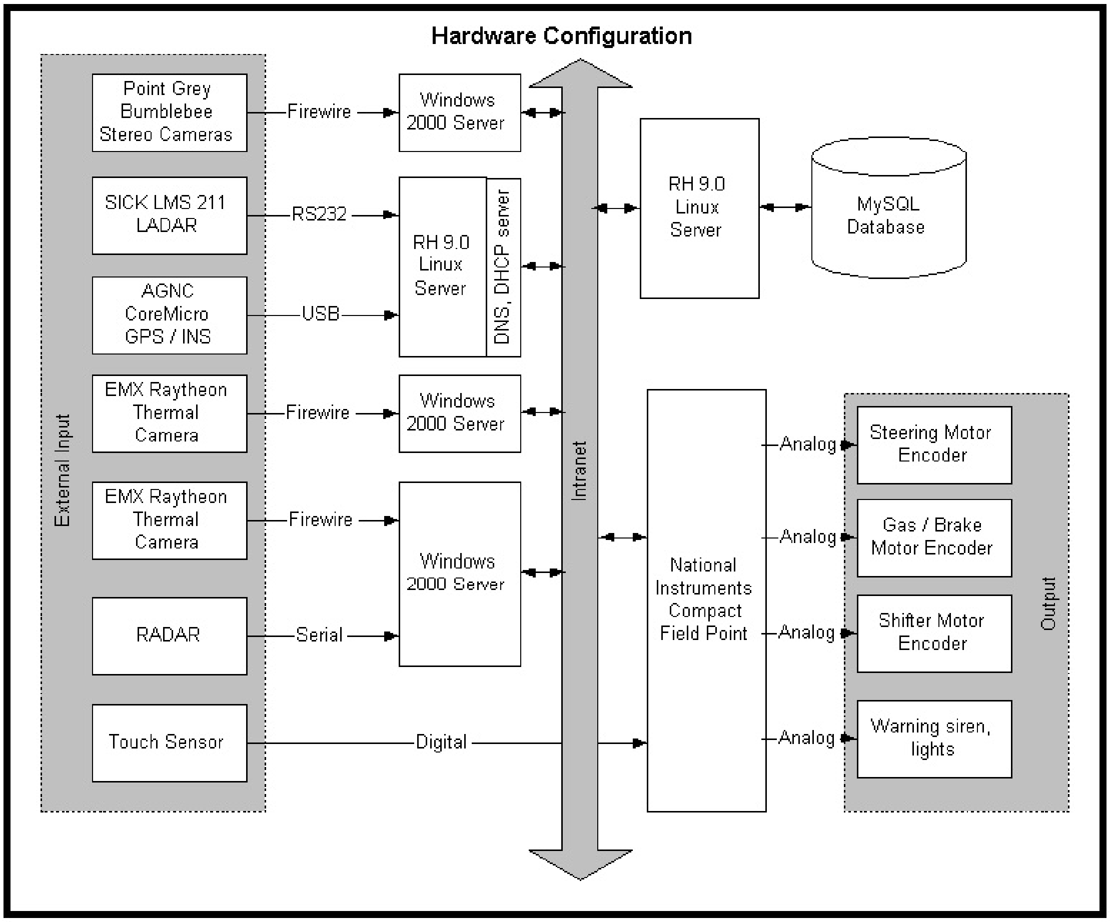

Figure 2: System hardware configuration

2. Describe the methodology for the interpretation of sensor data, route planning, and vehicle control. How does the system classify objects? How are macro route planning and reactive obstacle avoidance accomplished? How are these functions translated into vehicle control?

The Behavioral Control System utilizes a distributed computing model to achieve real time control with multimodal sensor suffering minimal overhead from data fusion. In this framework, each sensor supplies data to one or more software control modules. Each module is assigned a specific task, and returns the path it believes the vehicle should travel for the next few seconds. If the input sensor data satisfies the task, its decision is sent to a centralized processing module called the Arbitrator. The Arbitrator accumulates the decisions from each of the distributed components. Based on the current state of the vehicle (taking into consideration conditions such as whether the vehicle is driving on asphalt, sand, vegetation, etc.), the Arbitrator weights the importance of the task and decides on the best path to travel. See Figure 3.

The AR Challenge Vehicle uses LADAR with a 100 degree field of vision aimed directly in front of the vehicle. This sensor can detect positive obstacles and can be used to look for other vehicles.

Macro route planning is based on a shortest-path search between each of the waypoints. The desirability of each one-meter square is based on whether the square contains a road, its slope, vegetation, water, etc. At specified time intervals, this mapping engine provides steering information to the Arbitrator based on the current GPS coordinates. The AR Challenge Vehicle will use the macro route planning algorithm to drive the calculated best path, using vehicle speed monitoring, to drive the AR Challenge Vehicle successfully and safely from waypoint to waypoint. If an unplanned obstacle is encountered, it will be added to the AR Challenge Vehicle's internal database and a new path will be calculated and then implemented.

Some of the above-mentioned sensors are used to sense the state of the AR Challenge Vehicle. The AR Challenge Vehicle will draw upon the data from the GPS/INS system for gross vehicle state information. The Arbitrator will poll vehicle feedback data to determine type and significance of vehicle malfunction. Similarly, a detection of zero or reverse (in a no command situation) velocity will prompt additional querying routines. Roll, pitch, or yaw values outside of predetermined parameters will trigger the e-stop circuitry.

The AR Challenge Vehicle reactive obstacle avoidance system is based on determining specific paths available out to the stopping distance of the challenge vehicle. By using a northerly arcs calculation, the vehicle can drive with the steering wheel either all the way right, left, or straight ahead. Steering, braking, and throttle are controlled by the decisions of the Arbitrator, which sends commands to the National Instruments to accomplish the actuation of the individual components.

d. Internal Databases

1. What types of map data will be pre-stored on the vehicle for representing the terrain, the road network, and other mobility or sensing information? What is the anticipated source of this data?

A navigational database is based on commercial and freely available data obtained from Internet and other public resources. The data varies from one to 30 meters resolution. Information contained may include presence of a road, an off road track, elevation, slope, vegetation and water probability. The sources for the data used to create the database tables are primarily from the United States Geological Survey (USGS). The source used for elevation data is the National Elevation Dataset (NED) at 30-meter resolution in ArcGrid format. The National Land Cover Data (NLCD) from the USGS was used for water, vegetation, and surface type, also in NED at 30-meter resolution, ArcGrid format. The isRoad variable was extracted from TIGER 2000 line files, at 1m accuracy. Topologically Integrated Geographic Encoding and Referencing (TIGER) 2000 hydrography line files in combination with the NLCD increased the accuracy of the water variable. A Spatial Analyst extension tool created all of the tables used.

e. Environment Sensing

1. What sensors does the challenge vehicle use for sensing the environment, including the terrain, obstacles, roads, other vehicles, etc.? For each sensor, give its type, whether it is active or passive, its sensing horizon, and its primary purpose?

Sensor	Mfg	Qty	Model	State	Sensing Horizon	Primary Purpose
Two-lens stereo camera	Point Grey Research	4	Bumblebee	Passive	100 degrees x 50m	Finding surface normals and ranging data, and obstacle detection and crash avoidance.
LADAR	SICK	1	LMS 211- 30206	Active	100degrees x 30m	Detecting obstacles
Thermal camera	FLIR Systems	1	A20M	Passive	100 degrees x 50m	Detecting presence of humans, obstacles, roads, non-roads, vegetation, rocks, and ground.
Red, Green, Blue Camera	Allied Vision Systems	1	Dolphin	Passive	100 degrees x 50m	Classify terrain conditions
GPS/INS	American GNC	1	Coremicro UNUCN1	Passive	N/A	Determining latitude, longitude, elevation, velocity, roll, pitch and yaw
Touch Sensor	Axion, LLC	4	MetalSense B1	Active	100 degrees x 01m	Custom-manufactured sensor to notify NI system of physical contact

Table 1 – Sensor Descriptions

One other terrain sensor Axion, LLC is using is a 77 GHz three dimensional tracking obstacle detection RADAR. This sensor is built by Epsilon Lambda Electronics (Model #ELSC71-1B) located in Geneva, Illinois.

This RADAR unit has the following specifications:

- FM-CW Ranging Radar – Millimeter Wavelength (High Resolution)
- High Gain Antenna with range up to 110 meters
- Azimuth and Elevation Target Angle Determination
- Azimuth scan with selectable Narrow (+/- 8) or Wide (+/-20) Field-of View
- Low Phase Noise Transceiver
- Operable from Battery Supply Voltages

Obstacle data reported by this particular sensor includes range, azimuth angle, elevation angle, relative velocity, and signal return amplitude.

2. How are the sensors located and controlled? Include any masts, arms, or the tethers that extend from the vehicle?

The camera systems will be mounted within a protective housing, using the casing to protect them from the elements and environmental insult. The protective housing will be mounted atop the AR Challenge Vehicle, in a manner that allows the greatest forward field of view. The LADAR will be mounted near the front of the vehicle. The RADAR will be mounted near the front of the vehicle. The GPS/INS system will be mounted on the inside of the Challenge Vehicle. Three touch sensors will be mounted in the front of the vehicle.

All the cameras are mounted in a polycarbonate housing near the front of the AR Challenge Vehicle. This includes the Bumblebee cameras, the color camera, and the FLIR camera. The glass portion of the light bar area that holds the mounted FLIR camera has a piece of infrared glass in the section in front of the camera field of view (FOV).

f. State Sensing

1. What sensors does the challenge vehicle use for sensing vehicle state?

The AR Challenge Vehicle will use the American GNC Coremicro Land Navigator (LN) AHRS/DGPS/INS system to determine the geolocation of the AR Challenge Vehicle.

Heading, roll, and pitch will be introduced into the AR Challenge Vehicle's computer systems through the Coremicro's serial port (RS232) interface to the servers.

2. How does the vehicle monitor performance and use such data to inform decision making?

By using all available sensor data (GPS, IMU, etc.) the AR Challenge vehicle will use software to create a single vehicle navigation state vector (IMU+GPS) and a diagnostic state vector of the AR Challenge Vehicle's health. The challenge vehicle control software will monitor both navigation and vehicle health during the race. Information from both the navigation and vehicle state vector's will determine how the challenge vehicle proceeds. If either state vector reports irregularities, the vehicle will make needed adjustments.

g. Localization

1. How does the system determine its geolocation with respect to the Challenge Route?

The AR Challenge Vehicle determines its geolocation with respect to the Grand Challenge route with the coremicro LN Land Navigator Inertial Navigation System (INS). The LN's proprietary algorithm integrates information from its WAAS-enabled, differentially corrected 12-channel GPS receiver with its MEMS-based Inertial Measurement Unit (IMU) and velocimeter measurements to provide INS accuracy of less than 1m.

2. If GPS is used, how does the system handle GPS outages?

In the event of GPS outages, the coremicro LN's dead reckoning system calculates the current location by integrating velocity and 6-axis acceleration measurements since the last known location. This same system is also used to validate the GPS accuracy, minimizing any GPS "jumps" that may occur with reduced satellite coverage.

The AR Challenge Vehicle will also continue to determine if the GPS signal has be reacquired and use that data to update its inertial navigation information.

3. How does the system process and respond to Challenge Route boundaries?

At the beginning of the DARPA Grand Challenge race, the participants are provided with GPS waypoints and error margin information. The AR Challenge Vehicle recognizes these boundaries in its mapping engine, and makes all decisions based upon the knowledge that it should not pass these boundaries. The importance of the boundaries is represented as a weight in the Arbitrator's state machine, sufficiently decreasing the probability that the AR Challenge Vehicle will not navigate past the boundaries.

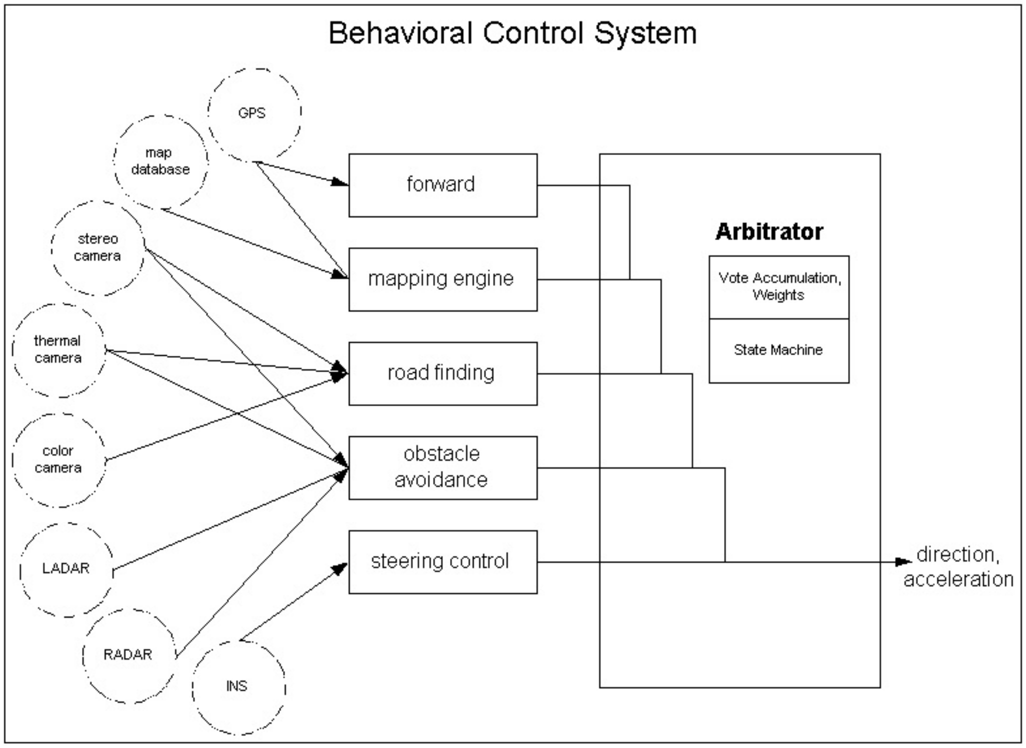

Figure 3: Behavioral Control
Integrates sensor information to determine course

h. Communication

1. Will any information (or any wireless signals) be broadcast from the Challenge Vehicle? This should include information sent to any autonomous refueling/servicing equipment.

No signals will be broadcast from the AR Challenge Vehicle during the DARPA Grand Challenge.

2. What wireless signals will the Challenge Vehicle receive?

The AR Challenge Vehicle will receive GPS signals, including WAAS and Differential corrections. The vehicle uses American GNC Coremicro Land Navigator (LN) GPS/INS which can receives signals from its satellite. This is a commercially available unit and signal.

i. Autonomous Servicing

1. Does the system refuel during the race? If so, describe the refueling procedure and equipment.

The AR Challenge Vehicle does not refuel during the race.

2. Are any additional servicing activities planned for the checkpoint? If so, describe the function and equipment.

The AR Challenge Vehicle does not require additional servicing during the race.

j. Non-Autonomous Control

1. How will the vehicle be controlled before the start of the challenge and after its completion? If it is to be remotely controlled by a human, describe how these controls will be disabled during the competition.

To control the AR Challenge Vehicle before and after the race, a human will disengage the steering servo using the steering servo disengage lever. The human will then have control of the stock accelerator pedal, stock brake pedal, transmission shift, and steering wheel. Actuators can be individually actuated using the EMC touch key interface.

A human operator will control the AR Challenge vehicle before and after the competition of the race by using the steering wheel, accelerator, brake pedal, and transmission shifter to control the vehicle. These items work on the AR Challenge Vehicle just like all standard vehicles.

2. If it is to be remotely controlled by a human, describe how these controls will be disabled during the competition.

For testing purposes only, the AR Challenge Vehicle may be remotely controlled by a human via an Ethernet radio link. During the DARPA Grand Challenge, these radios will be removed from the vehicle, disabling the ability of this function to operate.

1. System Performance

a. Previous Tests.

What tests have already been conducted with the Challenge Vehicle or key components? What were the results?

1) SICK LADAR: The LADAR unit has been installed on the AR Challenge Vehicle and the vehicle has been driven around the San Diego test area. Data was received and will be incorporated into the Inertial Measurement Unit at a later date to help build 3-D map processing.

2) GPS: The AR Challenge vehicle's GPS system has been tested for accuracy against other COTS GPS system. The accuracy and dependability has matched the team's hopes when the unit was purchased.

3) ODB-II Information: Utilizing the ability for a 1994 Jeep Grand Cherokee to attempt to deliver vehicle data to a COTS monitor has proven to be less than useful information. The team continues to do cost analysis of the race use of this information.

4) Bumble Bee Cameras: These stereo cameras have been tested under numerous conditions. The results have confirmed the team's belief in this technology.

a. Planned Tests

What tests will be conducted in the process of preparing for the Challenge?

The testing strategy establishes reliable control of each component separately before the components are integrated. Using the human as the ultimate controller of all tests except the final test, we ensure software or hardware errors can be safely detected and corrected by a trained driver. At this time, the tests below have not been performed, but will be conducted over the next few months. The goals of the future tests will demonstrate safety and usage for:

1) Obstacle detection
2) Obstacle avoidance
3) Waypoint following via GPS
4) Path following
5) Software adaptableness for "drive-by-wire"

Planned tests will be held on private property outside of San Diego, California. This land includes both paved and desert terrain.

As Planned Tests are performed they will occur approximately once a week.

In addition, the following sensor testing will be performed:

1. E-Stop: Tested extensively to insure safety to all.
2. Stereo Cameras: Terrain classification, negative obstacles, and other tests will be performed on this sensor.

3. RADAR: range, azimuth angle, elevation angle, relative velocity, and signal return amplitude.
4. Component failure testing: Since the AR Challenge Vehicle cannot operate without power, testing will be done to insure that the vehicle has power the whole race. These tests will include cutting power to individual sensors, computers, and support electrical units.
5. IR Cameras: Video will be digitalized to make sure that different objects are classified correctly.

Test 1: Radio Control (RC) Challenge Vehicle

The AR Challenge Vehicle will be controlled by a 75MHz transmitter, where multiple servo-driven micro switches will actuate the acceleration, braking, and steering. The AR Challenge Vehicle will be directed from inside the vehicle by a human Evaluator. The Challenge Vehicle will run a test course in a private lot to establish complete controllability. Prior to the Grand Challenge event, the radio control equipment will be removed from the vehicle.

Test 2: Control of vehicle through real time controller

The Evaluator is seated inside the vehicle next to the real time controller, using a keyboard and monitor to interface to the real time controller. The Evaluator specifies the desired course around a private lot, using predetermined waypoints. The vehicle drives through this course, testing the integration of the real time controller to the vehicle mechanics. The Evaluator sitting inside the vehicle may at any time interrupt the vehicle by manual E-stop or releasing the lever connecting the steering, gas, and braking control equipment.

Test 3: Environmental sensing to direct vehicle path

A destination waypoint is provided to the vehicle software. The vehicle reads the incoming sensor data, and executes the behavioral control algorithm to guide the vehicle to this waypoint. For this test, the result of the behavioral control algorithm is displayed to the user on a monitor. The Evaluator executes the commands displayed on the screen, simulating control of the vehicle while exclusively testing the environmental sensing and behavioral control systems.

Test 4: Complete integration of real time controller with behavioral control system

A destination waypoint is specified. For this test, Evaluators are present inside the vehicle in case of error, yet the vehicle is fully autonomous. The vehicle accepts input from the external sensors, executes the behavioral control algorithm, and provides this result to the real time controller that is connected to the vehicle mechanics. An Evaluator sitting inside the vehicle may at any time interrupt the vehicle by manual E-stop or releasing the lever connecting the steering, gas, and braking control equipment.

Test 5: Increasingly difficult terrain

After test 4 has been successfully passed, the vehicle will be ready to tackle increasingly difficult courses using the same testing paradigm as test 4. The AR Challenge Vehicle will move from the private lot to other locations offering varied terrain such as rocks, sand, vegetation, and hard-packed dirt. The objective is to understand and overcome any limitations of the vehicle, stressing the limits of tilt, speed, agility and control. An Evaluator sitting inside the vehicle may at any time interrupt the vehicle by manual E-stop or releasing the lever connecting the steering, gas, and braking control equipment.

3. Safety and Environmental Impact

a. What is the top speed of the vehicle?

The top speed of the AR Challenge Vehicle is estimated to be approximately 100 miles per hour, as per manufacturer specifications. However, sensing range and programming constraints limit the vehicle's speed to 50 mph. The inclusion of Kevlar tires would allow for a higher maximum speed, but there are tradeoffs that have yet to be truly evaluated at this time.

b. What is the maximum range of the vehicle?

The maximum range of the AR Challenge Vehicle is estimated to be 350 miles.

c. List all safety equipment on-board the Challenge Vehicle, including

1. Fuel containment

The AR Challenge Vehicle will utilize a standard Department of Transportation (DOT) certified integrally mounted fuel tank. This stock Jeep gas tank will hold all of the unleaded fuel the vehicle will need to drive the race.

2. Fire suppression

The AR Challenge Vehicle will have a fire suppression system which detects and extinguishes engine, cargo, computing, and passenger compartment fires. If exposed to a range of high temperatures the fire suppression's pressurized hoses will burst releasing gasses that will suppress any fires on board the challenge vehicle.

If the fire suppression system has been activated, the challenge vehicle's computer system will turn off effected equipment or even initiating a software based E-Stop.

3. Audio and visual warning devices

At the center of the top of the vehicle, a flashing light will be mounted indicating the vehicle is operating in autonomous mode. The vehicle will have three red lights located at the back of the vehicle to indicate the vehicle is braking, which are stock from the automobile manufacturer. Two lights are mounted at either side of the vehicle, and one light is mounted slightly higher at the center of the back of the vehicle.

The AR Challenge Vehicle will have several flashing lamps mounted externally as well as multilingual signs warning to stay a safe distance from the automated challenge vehicle. A audible warning device will be utilized which meets DARPA requirements indicating the challenge vehicle is under automated control. This two tone (Hi – Lo) siren emits an audible warning of up to a 113 dB.

d. E-Stops

1. How does the Challenge Vehicle execute emergency stop commands? Describe in detail the entire process from the time the on-board E-Stop receive outputs a stop signal to the time the signal is cleared and the vehicle may proceed. Include descriptions of both the software controlled stop and the hard stop.

The AR Challenge Vehicle at rest has a standard position with the brake applied and the transmission in park. At any time, for the vehicle to move, the vehicle requires positive power to the servo motors to defeat the natural, at rest, tendency of this position. The single servo motor for gas/brake function requires movement of the braking arm to release brake pressure and swings through to operate throttle (this is standard COTS as per manufacturer).

For the different E-stop scenarios the vehicle acts as follows:

1) If the vehicle experiences **loss of wireless signal**, the National Instruments (NI) system applies brake, continues to steer, and shifts into park after achieving 0 mph, and waits for reestablishment of wireless contact.
2) If the vehicle receives a **Soft E-Stop** command, it reacts as in case (1) above although it will be programmed to wait for a proceed signal. The vehicle will stay in this state until a proceed signal is received.
3) If the vehicle receives a **Hard E-Stop** signal, the NI system will apply the brake and shift to park. Ground connection will be disabled to the servo motors, causing them to revert to the at rest position, which is full brake and in park. The NI will disable the ground connections for the vehicle's ignition system and the fuel pump to shut down the vehicle's engine. The steering servo motor will not lose power during a Hard E-Stop.

If one of the computers fails, a Hard E-Stop will be performed.

2. Describe the manual E-Stop switch(es). Provide details demonstrating that this device will prevent unexpected movement of the vehicle once engaged.

The AR Challenge Vehicle will utilize a number of red mushroom pushbutton switches, similar to an emergency OFF switch of the type found in a gas station or on a piece of high-power electrical equipment. The switch shall be labeled as "E-STOP" in lettering large enough to be easily visible at a distance of at least ten feet in English and Spanish. Three switches will be located centered in the rear and centered on each side of the Challenge Vehicle. In the event that any of these switches are activated, the vehicle will react as it would for a **Hard E-Stop** wireless signal described above.

3. Describe in detail the procedure for placing the vehicle in “neutral”, how the “neutral” function operates, and any additional requirements for safely manually moving the vehicle. Is the vehicle towable by a conventional tow truck?

The AR Challenge Vehicle is not designed to use “neutral” in normal autonomous operation. The AR Challenge Vehicle either will be in motion, or stopped via the braking system. When an “E-stop” signal is received it will bring the AR Challenge Vehicle to a halt. When motion is determined to have ceased, the AR Challenge Vehicle will be set to “Park” until a resume signal is received.

The AR Challenge Vehicle can be set manually to “neutral” by removing a pin from the shifting servos’ arm where it connects to the factory shift arm to allow for towing.

The AR Challenge Vehicle is towable using a standard flatbed automobile tow truck. If required, the servo motor that controls acceleration and braking can be disabled by use of a single, manufacturer supplied switch. The steering gearing may be disconnected by a manufacturer-supplied lever (standard with equipment), and control may be turned over to a person. These emergency release mechanisms will be highlighted and flagged with instructions in English and Spanish clearly posted. The mechanics to control the AR Challenge Vehicle do not hinder standard acceleration, braking, and steering. Because of its foam filled tires, the AR Challenge Vehicle should not be towed above speeds of forty five miles an hour for long periods of time.

e. Radiators

1. Itemize all devices on the Challenge Vehicle that actively radiate EM energy, and state their operating frequencies and power output. (E.g., lasers, radar apertures, etc.).

Device:	SICK LMS-211 single-axis LADAR
Operating Frequency:	Infrared
Power Output:	Class 1 Laser

2. Itemize all devices on the Challenge Vehicle that may be considered a hazard to eye or ear safety and their OSHA classification level.

Except possibly the DARPA required audible warning device, there are no devices on the AR Challenge Vehicle that are considered a hazard to eyes or ear safety.

3. Describe any safety measures and/or procedures related to all radiators.

The AR Challenge Vehicle’s SICK LSM -211 LADAR uses a class 1 laser, which in not hazardous to eyes or competent of acting as a source of ignition. Therefore, it is unnecessary to take safety precautions related to the AR Challenge Vehicle’s only radiator.

f. Environmental Impact

1. Describe any Challenge Vehicle properties that may conceivably cause environmental damage, including damage to roadways and off-road surfaces.

The AR Challenge Vehicle is a standard production vehicle with an internal combustion engine. As such, there will be a certain amount of tailpipe emissions, which have been shown to contribute to local air pollution. Ground contact will occur via four rubber-covered wheels, which most likely will cause damage to any plants or animals that are located in the vehicle path. Certain of the fluids that the AR Challenge Vehicle will use are capable of causing harm to the environment. Among these are motor oil, power steering fluid, brake fluid, automatic transmission fluid, gasoline, and anti-freeze.

Normal operation of the AR Challenge Vehicle shall minimize contamination of the environment by these fluids.

2. What are the maximum physical dimensions (length, width, and height) and weight of the vehicle?

The maximum physical dimensions of the AR Challenge Vehicle are an overall length of 179 inches, overall width of 72 inches, and an overall height of 58 inches. The wheelbase is 106 inches, and the gross vehicle weight will be about 5,500 pounds.

3. What is the area of the vehicle footprint? What is the maximum ground pressure?

The contact patch for the AR Challenge Vehicle's tire footprints is about 150 square inches. Assuming a 30% tread void given our B.F. Goodrich Mud/Terrain T/A® tires, the maximum ground pressure is 32 psi.

360 Degree Video Capture

If race day video capturing is allowed, Axion, LLC will use a 360 degree camera to capture video during the DARPA Grand Challenge. The technology used by this camera was developed with DARPA and all of the parts are publicly available:

Camera	http://www.remotereality.com/security/netvision360.html Model B
Starter System & Case	http://www.iqeye.com/res/starter.htm

If approved by DAPRA, this 360 degree video capture camera system would be connected, with standard cables, to the Challenge Vehicle's Dell (Serial # CSHH421) 2650 server. The video would be written to an internal hard disk (36M size), on the server, during the race. There is a 10 hour video capture limit for this system.