DARPA Grand Challenge

Technical Paper for TerraMax

Submitted by Oshkosh Truck Co.
and
The Ohio State University

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 vehicle platform is an Oshkosh Trucks MTVR ModelMK23. A brochure with technical specifications can be found at http://www.oshkoshtruck.com/pdf/Oshkosh_MTVR_brochure.pdf, which we also attach here. The minimum turning radius is 42.7 feet. However, if necessary, in "robot" mode (explained below) the vehicle will be able to turn a tighter corner in multiple back-forth motions. The vehicle can traverse a 60% grade and a 30% side slope. The vehicle cab and exhaust stack have been shortened to the dimensions given in section 3.f.2 to accommodate known requirements of the course.

Figure 1. TerraMax arriving at the OSU Campus.

Ground contact is by means of 6 wheels. The geometry is shown in Figure 2, below.

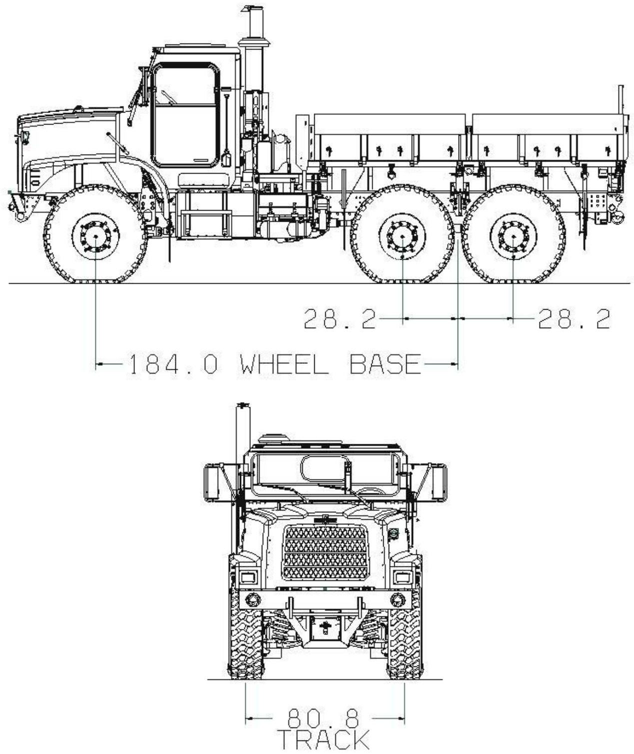

Figure 2. Size and geometry.

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

The Challenge Vehicle (TerraMax) is based on an Oshkosh truck adjusted for drive-by-wire capability. The truck has six wheels, steering is accomplished with a servo motor turning the steering wheel, an actuator to move the brake pedal and direct electronic control of throttle and transmission.

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

The drive-by-wire capability was provided by additional components.

Steering actuation is accomplished through the use of a Rockwell Automation motor and a Rockwell Automation controller. The motor is attached to an auxiliary input shaft on the steering gear. The existing steering wheel allows for manual override.

Throttle control will be accomplished through interaction with a variable Pulse Width Modulated output from a D/A converter directly into the Engine Speed Input on the CAT engine ECU. The expected signal is a 500 HZ +/- 20 Hz centerline, 8.0 V peak PWM. By varying the duty cycle from 25% at low idle to 75% at high idle, the full RPM governed range can be attained. Since the low and high idle to direct RPM values are self calibrated by the engine ECU

every time the vehicle is started, the engine speed on the J1939 data bus will have to be monitored and the computer will need to do an automatic self calibration.
The braking system, developed by Bendix, uses an electropneumatic actuator to press the brake pedal. Automated braking is accomplished using a second brake manifold and check valves installed in parallel with the existing pneumatic brakes. Air pressure into the brake by wire manifold is regulated by an electropneumatic regulator (ControlAir 500x) supplied from the wet tank. The control input to the electropneumatic regulator is an analog voltage (1-9VDC). The pressure at the outlet of the electropneumatic regulator is monitored and verified using a Honeywell ML200PSIPC pressure sensor (0-200 psi) with an analog voltage output (0.5 – 4.5VDC).

Current requests for shifting the transmission are Neutral, Reverse and Drive. Basic information available to us shows that we will connect to the WTEC-3 ECU through the Secondary Shifter pins. The 5 pins required are a parity bit and bits 1,2,4 and 8. Depending on how these pins are activated, a shift request will result. The activationthrough open collector optoisolator in parallel with the stock transmission control keypad.

b. Power.
   1. What is the source of Challenge Vehicle power (e.g., internal combustion engine, batteries, fuel cell, etc.)?

Power is from a diesel engine.

The diesel engine will supply both driveline power and electrical power for instrumentation and drive-by-wire components.

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

The engine can provide 425 hp (317kW).

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

The vehicle will carry 156 gallons of #2 diesel fuel.

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

The TerraMax will have 6 Pentium 4 machines running Linux or QNX operating systems. The primary functions of each are:

- *Map and Route Planning*
- *Vision (2 computers)*
- *Sensor data and fusion*
- *Main Control*

- *Health monitoring*

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?

Sensor data is interpreted by the "Surround Sensing/Sensor Fusion Module" explained below. Route planning at the high level is accomplished by the "Map and Route Planning Module", and at the low level dealt with within the "Situation/Control Logic Module", which also generates the set points for the lowest level control loops. Reactive obstacle avoidance is within the Situation/Control Logic Module, which uses information provided by the Surround Sensing/Sensor Fusion Module and generates a set of trajectory points with constraints provided by the "High Level Terrain Classifier Module". Details are provided below.

The TerraMax Control Logic is made up of a number of blocks: some always active and some active on demand. The established structure allows separate and somewhat independent development. It also allows continual expansion of different and more complex cases and situation to be addressed during the development cycle.

We are developing the following modules:

- *Map and Route Planning Module*
- *Surround Sensing/Sensor Fusion*
- *High Level Terrain Classifier*
- *Situation/Control Logic*
- *Alarm*
- *Roll-back Analyzer*

In what follows, we shall introduce the Modules their inputs outputs and their goals.

Module 0: Map and Route Planning Module

This module deals with the "way points" provided and accomplishes the high-level route planning. A digital terrain map is being appended with weights to generate a so-called "hospitability map" and a "synthetic inclination map", presently manually using photographic data. (These maps will be updated in real-time to reflect terrain anomalies discovered by the Surround Sensing/Sensor Fusion Module.) A D-Star algorithm is then used to calculate the "best" route and provide it to the Situation/Control Logic Module. As implemented, the Map and Route Planning Module will also provide time estimates for traversing segments and alternate routes. The Module will be re-called as necessary by the Roll-back Analyzer Module.

Module 0 also determines if the waypoints are too close to do additional path planning, and also retains data on path segments that were considered before the race.

Module 1: Surround Sensing and Sensor Fusion

Surround Sensing basically generates a map surrounding the vehicle, classifying various objects and regions.

There are a number of accomplishments expected of Module 1:

1. *Providing input for general Terrain Classification*
2. *Short distance trajectory planning*
3. *Medium distance trajectory planning*

A series of Quality Factors will be calculated. These will include:

- *Lane identification*
- *Surface roughness (bumps)*
- *Surface softness (squishiness!)*
- *Positive obstacle caliber*
- *Negative obstacle caliber*

Module 2: High Level Terrain Classifier

The High Level Terrain Classifier Module decides on the surrounding terrain and affects the type of "Behavior" TerraMax has to accordingly have.

The Terrains we are initially specifying are the following:

- *Roadway*
- *Open—smooth*
- *Open--rough*
- *Uphill rough*
- *Downhill rough*
- *One-side fall*
- *Robot*

Roadway: *Classification as a Roadway implies the existence of lane-markers. Roadways also should match identification on the map database.*

The quality/reliability of the lane determination (by map and image processing) will be calculated.

The standard OSU lane following controller will be used.

Open—Smooth and Open—Rough: *Smooth or Rough open terrain can be classified based on both laser data and suspension readings. It will affect speed and possibly settings related to sensors and cameras.*

"Lane determination" should still be active with weight attached to trails identified by the map.

Uphill—Rough and Downhill—Rough: *This is a self-evident terrain, and TerraMax is to move slowly with appropriate setting of brakes and gears. It also affects the sensor suite.*

One-side fall: *This terrain class is separated so that motions to the dangerous side can be curtailed. The possibility of having this type of terrain can be pre-identified from maps, and verified by sensors.*

Robot: *"Robot" is a special terrain/location where the vehicle has to go through a specific exercise, possibly with a set of predetermined operations, to go past an obstacle or through a narrow constrained passage.*

Examples where Robot behavior may be needed include underpasses, gates, sharp turns at roadway intersections and possible passage through mazes of natural and synthetic obstacles.

Module 3: Situation and Control Logic

The "Situation and Control Logic" (SCL) is the Module that manages the full system. It establishes a multi-level hierarchy (a subsumtion architecture) that uses the other modules to provide sensing, situation selection and real-time control.

There are two basic levels for the tasks.

At a higher-level SCL will have a sub-module comprising the over-all situation logic.

Situation Logic:

- *Checks which stage of the race we are in*
- *Obtains way-point pair we are in*
- *Obtains terrain classification which is current*
- *Calls Control or Robot Motion or Rollback Analyzer as appropriate*

Control:

The Control sub-module is similar to both the Ohio State University Demo'97 configuration and the Ohio State University Demo'99 setup but modified to handle the obstacle avoidance requirements of an unstructured environment.

The Demo'97 vehicle had distinct longitudinal (speed and brake) and lateral (steering) control tasks. The speed is adjusted either in a pre-planned way or affected by sensor input in the car following (ACC) mode. The speed adjustment in the Demo'99 vehicle (where there was no car following) was purely dependent on location, in fact on road curvature (determined from the map).

Steering in the Demo'97 vehicles was sensor driven, and software-initiated events could be introduced (to do lane change). The steering set point relied on a look-ahead scheme. The look-ahead point determination used a combination of outputs from radar and vision. These could be additionally affected by inertial motion determination.

The Demo'99 vehicle directly used GPS and inertial measurement data to match the map-based trajectory.

The TerraMax Control system can be the same as the 97-99 systems. Steering can be similarly oriented towards a "mid-roadway" look-ahead point. The only TerraMax specific issue would be in generation of this point.

The speeds need to be selected based on the Terrain Classifier and adjusted if TerraMax is following another vehicle.

Obstacle avoidance may be done using a path-elimination approach or a simplified potential field approach.

Module 4: Alarm

The Alarm Module will be on all the time tracking:

- *Sensors reading unreasonably large data*
- *Heartbeat not registering*
- *Actuators being sent unreasonably large desired values*
- *Too long time spent on a stage (could be in another module)*

This module could handle various other issues:

- *Changing allowed motions, limits.*
- *Emergency stops*
- *Changes due to bad sensors*
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Module 5: Roll—back Analyzer

The "Roll—back Analyzer" (RBA) is a new Module that requires further study. The concept is that, if the vehicle remains at the same site, or within a small boundary (location dependent), or cannot make reasonable progress to wards the next waypoint for an excessively long time (duration dependent), the system must retrace its recent motions and reevaluate decisions to generate an alternate path.

This implies a number of issues:

- *a time estimate is needed*
- *decision points need to be identified*
- *second and third choices at the decision points need to be retained in memory*

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?

There will be three types of maps. The first is the basic map of the area from the USGS data library, supplied by the OSU Mapping Center. This is being manually "weighted" to assign hospitability-weights based on photographic images and other known information and create the Hospitability Map. The third map is made of pre-run route segments that can be used when identified.

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.

Four SICK LADARs (Model: LMS 221) are to be used. These are 2-D laser rangefinders (active sensors) with 180 degree scanning spectrum and have maximum scanning distance of 80 meters The actual range, of course, depends on the reflectivity of the target, but our experience to date indicates that 40 meters is a reasonable minimum operational range. The 40-meter range satisfies the Demo III Experimental Unmanned Vehicle (XUV) Program Obstacle Avoidance Requirements of approximately 110 feet when traveling 40 mph on a downward 7% grade. The latency is approximately 30ms as currently configured.

They will provide the distance and the location information of the obstacles around the vehicle. Two will be mounted on the left and right end of the front bumper, and each facing forward with 60 degree to the bumper. The third one will be mounted on the back bumper facing backwards. Those three LADARs will be scanning at the bumper level, 2.5 ~ 3 feet from the ground, with a horizontal coverage parallel to the ground surface. The fourth LADAR will be mounted at the front end of the hood and face forward perpendicular to the ground (scanning is in the vertical plane). This one will provide distance and depth information of the negative obstacles (holes) in front of the vehicle.

The vision system consists of 6 CCD digital color cameras. Two pairs are used to provide stereovision information (both forward and rear looking). The two single cameras will sense the terrain in front and behind the truck and provide free-space estimation and path/road estimation.

The vision system is a work in progress with the system being developed and tested initially in Italy by Prof. Alberto Broggi's group. There are two aspects: Lane/Path determination and Free Space Detection. For Lane/Path determination the three algorithms developed so far are:
–Clustering based on color texture. This is a classical approach based on the assumption that the textures of the path and off-road present different visual characteristic. The performance of this approach is currently being assessed.
–Boundary detection using a genetic approach. This is similar to the work done for military mobile snowcat tracks detection at the pole, performed by Broggi's group. The main idea is to recover path boundaries by means of autonomous agents. It has been under development for three years, and has proven to be fast and effective. For snowcat track detection the system is able to detect track boundaries at up to 40 meters and the processing time is 8.6 ms on a 1.3 GHz PC.
–Lane/Path match using multi degree-of-freedom models. This is a new, highly complex approach currently under development. It is based on a match against a number of path models generated acting on a set of parameters. A multiresolution approach will be used to increase computational efficiency: initially the match will be performed against a low resolution model, then refined using the best matching models at higher resolutions. The process will be iterated until a satisfactory result it obtained.

Prof. Broggi's group already has multiple working lane/path recognition systems and the present endeavor is developing better ones with the new hardware available. In fact, the OSU group also has had 3 working lane recognition systems going as far back as Demo'97 using single B&W cameras.

The "Free Space Detection" approach is based on stereo and color match and similar to pedestrian detection as developed by Prof. Broggi's group. Visual information is processed in order to detect the portion of the terrain ahead where is should be safe to move (the free space). Objects are not classified. A stereoscopic technique is used for the localization of potential obstacles in generic unstructured environments. Each row of the left image is matched with the epipolar row of the right image. This creates a map of each object in the scene as well as the slope of the road. This approach is particularly suited for off-road environments since it does not rely on calibration of the vision system.

The constraint we have set for ourselves is the minimum response time of 500 msecs as mentioned in the Demo III documents. With single B&W cameras we have performed lane detection with a range of 75m with a frame rate of 20 frames per second on slower machines in a system we developed for Delphi/GM in 2001. As the present vision systems are all still in development, we cannot provide exact range and latency information. We can claim, however, that we are aware of the constraints and the implications.

The vision system image processing will be performed on two dedicated CPUs. The two CPUs will then communicate with the sensor fusion CPU via network/bus to provide the complete surrounding environmental sensing.

2 Eaton-Vorad radars are mounted (front and rear) for providing 150 m range target tracking.

12 ultrasonic sensors (Massa—8in to 14 ft) are mounted around the vehicle for short range sensing.

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

See answer above. No masts, arms or tethers are employed.

f. State Sensing.

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

Two GPS units (Novatel Propack -LB Dual freq) will provide the GPS information for route and mapping purpose. One c compass (Honeywell HMR3000) will provide the vehicle heading, pitch, and roll information at low speed or idle state. One inertial measurement unit (IMU) will measure the total accelerations and angular velocity of the vehicle. Individual wheel speed is available off the J1939 bus. We will also have access to vehicle and actuator sensors to determine throttle, brakes, and engine condition. All the sensing data will be collected for the data validation and sensor fusion processes. The result will represent the complete vehicle state.

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

The vehicle receives and deals with all sensor data with the Surround Sensing/Sensor Fusion Module. This includes GPS data, and all external and all internal sensors except the cameras. The cameras are handled separately by the Vision Module. Limit checks are performed by the Alarm Module. The Alarm Module also checks the "heartbeat" of all processors and furthermore monitors the timing and location bounds to see if the vehicle is "stuck". The Alarm Module can initiate appropriate action, ranging from adjusting sensor weights, operating conditions to initiating the Rollback Analysis Module. The Alarm Module will also check for excess deviations from the nominal path to ascertain that the low-level trajectory will not push vehicle out the route boundaries.

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

The vehicle will use differential GPS

2. *Novatel unit with Omnistar HP satellite differential GPS corrections. The stated accuracy of this configuration is less than 0.15 meter horizontal position error 99% of the time.*

With options 1 and 2, the IMU will be either Honeywell HG1700 or the Litton LN200. Option 3 provides an integrated IMU. A magnetic compass and dead-reckoning information will also be included in the navigation solution. Our current plan is to implement Option 2 as soon as funding is available.

For a limited duration loss of GPS (on the order of minutes) we expect this approach to yield successful navigation. It should be noted that we will be operating at reduced speeds in narrow corridors, and that in many cases corridor boundary information will be available from terrain sensors or proximity sensors.

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

The vehicle will use its inertial navigation software (which it will be using between GPS sample times anyway.) For a limited duration loss of GPS (on the order of minutes) we expect this approach to yield successful navigation. It should be noted that we will be operating at reduced speeds in narrow corridors, and that in many cases corridor boundary information will be available from terrain sensors or proximity sensors. Appropriate adjustments will be made for smooth reacquisition.

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

Challenge Route boundaries are inserted into the Maps as providing very high cost. Thus the high-level route planner will not specify a path crossing such boundaries. At the lower level the trajectory will be generated by the Control Module using a simplified potential field approach and additionally checked by the Alarm Module for approaching too close to the boundary. For waypoints very close to each other, boundaries are directly provided to the Sensor Fusion Module

h. Communications.
   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. A vehicle mounted camera will however be used to record the race, but it will not transmit any data. *There is no refueling during the race.*

   2. What wireless signals will the Challenge Vehicle receive?

Only those used by the DGPS.

   3. Autonomous Servicing

No autonomous servicing is planned.

i. Non-autonomous control. 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.

A switch will transfer the vehicle between manual and automatic operation. In manual mode the brake, accelerator, transmission will work as expected. Steering will still be accomplished using the steering wheel. In fact, manual intervention will override the steering and brakes even in autonomous mode.

2. System Performance
   a. Previous Tests. What tests have already been conducted with the Challenge Vehicle or key components? What were the results?

- No hardware tests related to autonomy have been performed as yet on the Challenge Vehicle. Sensors are being tested on different vehicles. We have been using and have experience with the SICK LADAR's and the GPS equipment.
- A simulation model of the Challenge Vehicle has been developed and the software modules are being tested on the simulation environment.
- Specific algorithms to be used (e.g. lane following) have been tested on a series of OSU autonomous cars during the last 6 years. The OSU team won the 1996 Ground Robotics competition, participated in Demo'97 (where OSU autonomous cars were driven 70 mph and performed autonomous lane change and passing) and participated in Demo'99 (where OSU cars performed GPS and map based driving).

- The University of Parma group developing the vision system has developed and tested a series of successful vision systems for autonomous vehicles during recent years. They have been testing the digital color cameras to be used.

b. Planned Tests. What tests will be conducted in the process of preparing for the Challenge?

Sensors and all sensor related software will be tested on an off-road vehicle purchased for this purpose. Placement of sensors on the test vehicle will be similar to the race vehicle.

Test locations are being developed for the test vehicle and the race vehicle at the TRC (Transportation Research Center) grounds in East Liberty, Ohio.

Final tests will be performed in California, near Barstow.

3. Safety and Environmental Impact
   a. What is the top speed of the vehicle?

The top speed of the vehicle under automatic control will be 50 mph. Further, the maximum speed will be constrained by the terrain classification of our current location as described in the attachment. The standard anti-lock braking system will be in place and operational.

The estimated stopping distance at 45 mph is 116 feet on pavement (u=0.90) and 151 feet off-road (u=0.5). We will conduct experiments at TRC to verify the stopping distances at various speeds and tire inflations.

b. What is the maximum range of the vehicle?

The maximum range of the vehicle is 600 miles.

c. List all safety equipment on-board the Challenge Vehicle, including:
   1. Fuel containment

Fuel is contained in a steel fuel tank.

2. Fire suppression

An automatic detection and suppression dry chemical fire extinguisher system from Ansul has been installed in the engine compartment in agreement with the NFPA (National Fire Protections Associations) standards for fire extinguishing systems for engine compartments of diesel-powered vehicles, in the cab in agreement with NFPA standards for electrical and fabric fires, and on the outside of the vehicle in proximity of the fuel tank to suppress any highly unlikely fires that may originate from the diesel fuel tank area. This system is an automatic detect system that is properly sized for the spaces it protects. There is a manual actuator located inside the cab and on the outside of the vehicle as well We also have a hand-held portable fire extinguisher in the cab. We will provide whatever equipment is required to meet DARPA safety *standards and specification. The fire detection and suppression system will also perform an automatic e-stop.*

3. Audio and visual warning devices

The vehicle will have at least two flashing lights mounted externally as well as an audible warning device meeting DARPA specifications.

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 receiver 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.

Hard e-stop: At the receipt of the "Hard e-stop signal" the full brakes will be applied. The emergency disable capability is provided by a relay in series with the ignition switch wiring and by an electropneumatic valve in parallel with the existing parking brake valve. The relay is normally open, and in that state the engine cannot be started or run. The valve is normally open venting parking brake pressure to the atmosphere and locking the truck brakes. Three manual switches mounted on each side and on the rear of the truck, are integrated with the DARPA/Omnitech Safety Radio system to control the disable functionality. The Alarm Module in the software will provide the software settings that will ascertain a status from which the system will not re-start without manual intervention.

Soft e-stop: Soft e-stop generates a "stop" sequence from the Control module that provides a braking sequence and a zero-speed command. The stopping duration is timed and is eventually added to the time-to-go calculations. The re-start is also passed on to the Control module and initiates a standard start operation.

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

The manual e-stop switches will be located at three locations outside the vehicle. They will perform a "Hard e-stop" as indicated 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 automobile tow truck?

The vehicle can be placed in "neutral" by pushing the neutral transmission button in the cab. If the vehicle is not in an operable condition, removal of a drive shaft between the transmission and the transfer case may be required before the vehicle can be towed. The vehicle is too large to be towed by a conventional automobile tow truck.

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.)

No "radiators" exist on the base vehicle. Of the add-on sensors, we list the following:

- *4 SICK LADAR's. They are Class 1 infrared lasers.*
- *2 Eaton Vorad radars. 24.725 GHz*
- *12 Ultrasonic transducers*

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

None.

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

None.

f. Environmental Impact.

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

No environmental damage other than any other large vehicle could cause.

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

The vehicle is 28' long, 98" wide (with mirrors removed), 98" high (with top of cab removed), and weighs 32,000#.

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

Vehicle footprint is based on six tires (type 16.00R20 XZL). The footprint is 230 square inches per tire and a maximum ground pressure of 30 psi.

Attachment 1: System Architecture and Speed Setpoint Selection

Adjustment of the system speed is based on a number of issues and can be explained with a basic understanding of the system architecture (See Figure 2):

1. The High Level Terrain Classifier and the Global Map determine the Basic Set Speed for the segment being traversed (table look-up). This speed will depend on road classification (primary, secondary) and if off road, the grade and surface conditions. The Sensor Fusion Module can trigger a change in the Terrain Classifier. (See Figure 3.)
2. The segment speed can also be changed by the "Personality", which (in this case) can become more "aggressive" near the end of the race.
3. As explained before "Robot" behavior is a separate setting.
4. During non-robot driving the speed can be adjusted in real-time by
    a. Following vehicle ahead (basically as we did in Demo'97), with set headway.
    b. Road curvature (as we did in Demo'99). See paper enclosed.
    c. By identifying an obstacle ahead, depending on decision to stop or maneuver around obstacle. (As in Demo III analysis)

Figure 4 shows the various modules that affect these decisions.

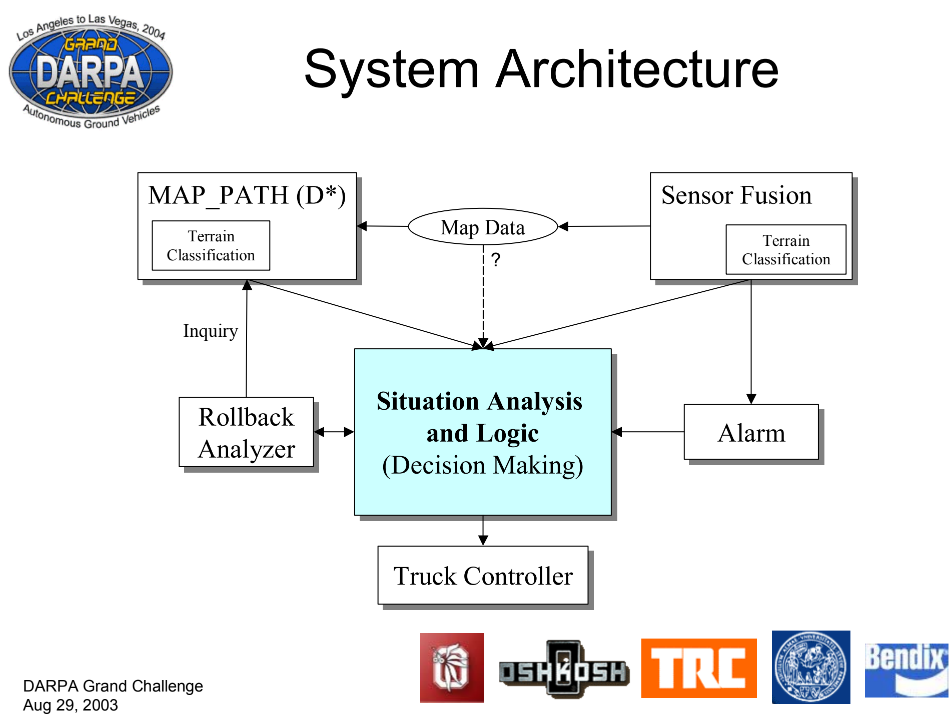

Figure 2. Basic TerraMax System Architecture.

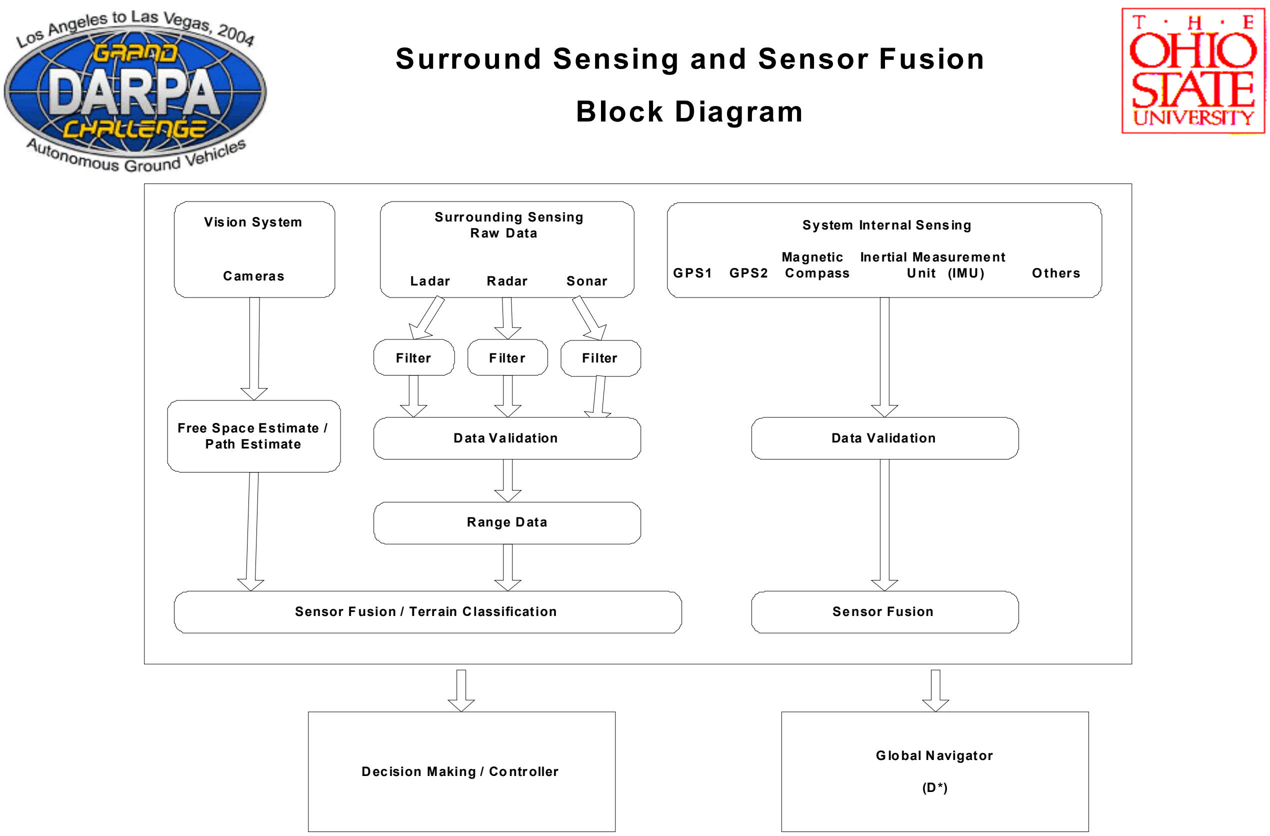

Figure 3. Sensor Fusion Module.

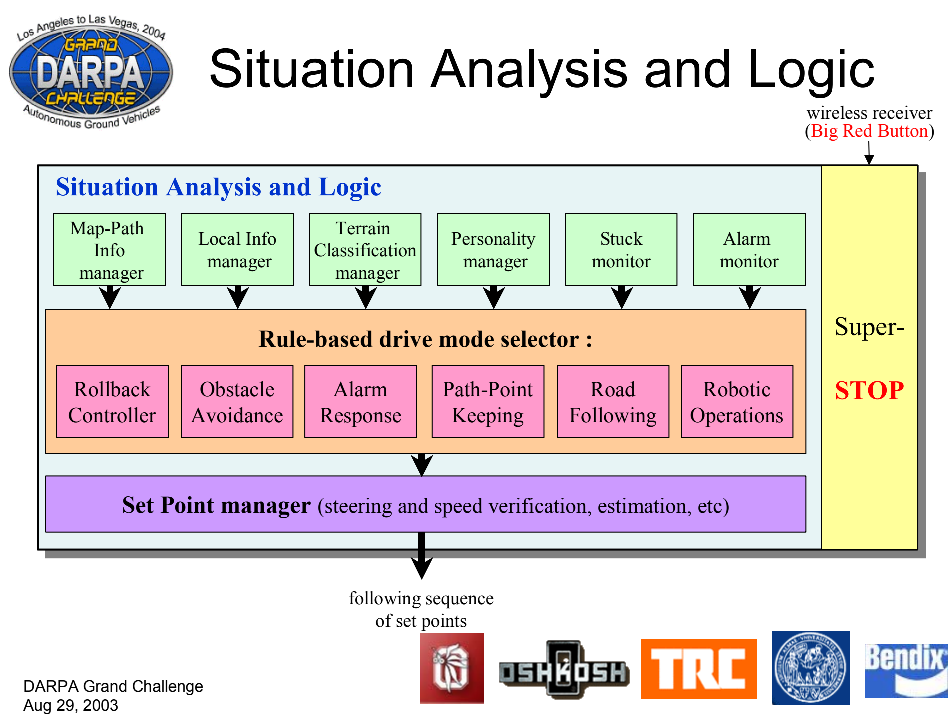

Figure 4. Situation Analysis Logic (affecting speed selection.)