DARPA Grand Challenge Technical Paper

Team Spirit of Las Vegas
Team Leader: Tiffany J. Kent

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1. System Description

a. Mobility

1) Ground Contact: The base vehicle design is a 2003 Honda 4X4 All Terrain Vehicle (ATV). Basic wheel footprint will not be altered.
   a) Wheelbase—50.7 in.
   b) Vehicle Width—Approx. 50 in. Vehicle width will vary as component testing and shrouding is developed.

2) Challenge Vehicle locomotion, steering and braking.
   a) Vehicle locomotion—649cc Honda Four Stroke gas-powered engine.
   b) Steering—production Honda ATV steering components will be used
   c) Braking—Production Honda braking actuators will be used. Brake actuators will be driven by PWM, high torque servos.

3) Describe the means of actuation of all applicable components.
   a) Steering--electric DC-geared motor driving chain and sprockets
      1. Sprockets, attached to the ATV steering yoke and electric motor output shaft, will be inter-connected with chain.
      2. The motor will be operated at 12 V_{DC} with high-resolution, linear potentiometer for feedback
   b) Transmission—standard Honda automatic torque converter with a 3-speed drive system. The transmission has three positions (FWD/NEU/REV). The transmission shifting mechanism is done through pulse-width modulated (PWM), high-torque servos.
   c) Brakes (front and rear)—actuated by two PWM high-torque servos, working in parallel.
   d) Throttle, ATV-- Throttle actuation will be controlled by PWM, high-torque servos.

   - Note: All servos are PWM high-torque, roughly 250 oz-in.

b. Power.

1) The DGC vehicle power (e.g., internal combustion engine, batteries, fuel cell, etc.) are as follows:
   a) Vehicle movement propulsion power is a 649 cc, Honda factory 4-stroke gas motor.
   b) Electrical system power is 28 V_{DC}, and 12 V_{DC} provided by 6 high-amp gel cell batteries. The 24 Volt system consists of two 600 amp batteries. The 12 Volt system consists of four 800 amp batteries.
2) Maximum Peak Power.
   a) ATV 4-stroke engine—(25 HP)—18,642 Watts
   b) Total wattage—18,642 Watts

3) The DGC vehicle will carry the following amounts and types of fuel:
   a) ATV 4-stroke engine—27-gallons, 91 octane unleaded fuel in saddle tanks mounted, one on each side of the vehicle.
   b) Total fuel capacity—27 U.S. gallons

c. Processing

1) Computing systems (hardware)—the ground vehicle will incorporate two computer systems that are broken down in the following (number, type, and primary function of each):
   a) Vehicle Control Monitoring System Computer (VCMS)—the VCMS runs the interfaces to 4 micro-controller chips (NetMedia BasicX 24), GPS, 3-axis gyro and heading system. A USB serial port expander provides the primary interface between the microcontrollers and the other RS-232 protocol hardware.
      1. Standard laptop personal computer (PC) based Pentium,
      2. 3.2-Ghz processor
      3. RAM—1024 MB
      4. 60 GB hard drive (HD)
      5. 4-USB port configuration
      6. 10/100T Ethernet connection
   b) Navigation and Video Processing Unit (NVPU):
      1. Apple G5, 2 GHz, dual processor
      2. 10/100T Ethernet connection
      3. HD storage space—320 GB
      4. RAM—8 GB
      5. 1394 IEEE Fire wire (video interface)

2) Methodology for the interpretation of sensor data, route planning, and vehicle control.
   a) Navigation sensing:

      1. Novatel ProPac-LB-HB satellite-based Differential GPS. This is a DGPS system with an estimated accuracy of 20 to 30 cm, 95% of the time. Specifications are in attached annex. This is the primary navigation unit.

      2. u-Blox GPS, with Wide Area Augmentation System (WAAS), is the secondary means for updating the vehicles position during the race.

      3. Video sensing is used to refine vehicle course. When the course narrows to a 10-foot wide corridor; the video system will not allow the vehicle to proceed unless it determines it is on a road, pathway, adjacent to barriers, etc. The vehicle will proceed at a slow speed, approximately 10 mph, until both video and navigation accuracy agrees.

4. Dead Reckoning (DR) method—the u-Blox GPS unit has a self-calibrating sensor feed for odometry. Hall-State proximity sensors are attached to each of the front wheels and two to the rear drive shaft. The GPS requires two more feeds for DR mode; a single-axis gyro and a logic high/low for forward or reverse motion. The Kalman filter on the GPS is self-calibrating. The greatest error in DR mode is no more than 5% of the distance traveled.

b) Terrain Sensing:

1. Shock monitoring System (SMS)—each shock is equipped with a string pot to determine the actual position of the shock (compressed or uncompressed). The string pots are used to determine the ride conditions as well as the loading / unloading of the wheels in turns. The system can report each shock individually or a sum value, or average, that weighs the ride condition over the past few seconds, and up to several minutes. This averaged value is a confidence factor used to determine how fast the vehicle should go over the various conditions of terrain. Additionally, the SMS will supply a weight-off-wheels (WOW) logic to the computer if for some unknown reason the vehicle happens to go airborne from a disturbance.

2. Attitude (3-axis gyro) – the gyro incorporates heading, acceleration and gyro sensors to determine the attitude, acceleration and heading of the vehicle. This information is used to prevent the vehicle from getting into a known bad state, based on terrain features. It is also used to limit the aggressiveness of the vehicle.

3. Video Processing—See Proprietary Annex

4. The NVPU will generate the ideal route dynamically and update as the vehicle drives. The route selections are optimized in the following order: 1) paved roads, 2) unpaved roads, 3) dry lakebeds, 4) digital elevation model data (DEM), and 5) satellite 24-bit color visual imagery (1 meter resolution). Some interpolations of the databases are done, but priority is basically in the order mentioned.

d. Internal Databases.

1) Types of map data to be pre-stored on the vehicle for representing the terrain, the road network, and other mobility or sensing information.

a) Commercially available DBs:

1. Digital Elevation Model (DEM) – USGS source at 30-meter resolution
2. Satellite imagery - 1-meter
3. Space Imaging, LLC, a TSOLV sponsor, is providing over 10,000 square kilometers of newly acquired 1-meter imagery (IKONOS satellite) for the geographic region of the race. This imagery is currently being updated to provide the most accurate source available. TSOLV team members will refine

the accuracy of the imagery, through standard ortho-rectified methods. Attached PowerPoint presentation depicts the area of coverage for the new imagery.

b) All other DBs will be built from hand (accuracy and format) from satellite imagery (1-meter) for route optimization are as follows:
   1. Paved roads
   2. Unpaved roads
   3. Lakebeds, Dry
   4. Lakes, Wet
   5. Rivers
   6. Fence lines
   7. Miscellaneous dangerous terrain features (canyons, cliffs, irrigation ditches, etc.

e. Environment Sensing.

1) Environmental Sensing. There are two sensors for determining the environment conditions. Only one of the two devices has a look-ahead capability. All sensors on the DGC vehicle are passive, low technical parts, except video processing. They are:

a) Shock Monitoring System (SMS) - also mentioned above in section 2.b.1
   1. The shock suspension uses SpaceAge Controls, string pots to determine the displacement of the shock in reference to neutral steady state.
   2. Each of the shocks is equipped with this device to determine displacement, acceleration and roughness of the terrain
   3. Additionally, full extension of all the shocks would result in a weight-off-wheel (WOW) condition signaling an airborne condition to the processor.

b) The video system is the only true look-ahead sensor, which determines the environmental conditions for "see-and-avoid" and "see-and-steer" modes.
   1. Early look ahead determines obstacles as far as 1,200 feet. Expected look-ahead detection at high speeds is between 800 and 1000 feet. At lower speeds are with more objects, the range can be reduced to 10-feet if necessary.
   2. The video system in "see-and-avoid" mode will detect and track objects via "optical flow" and obstacle identification, and/or obstacle avoid methods. Additionally, the system will always be selecting the shortest / optimal path, regardless of obstacle recognition, unless course boundaries are a factor.
   3. The video system has approximately 160-degree field of view (FOW) and will never allow the DGC vehicle to out turn the video system field of regard. Nor, will it allow collision with another vehicle. However, a sideward divergent collision is possible, but speeds for divergent are significantly reduced and extremely remote given the number of vehicles and course size.

2) Sensor location and control. The video system is mounted in a self-contained unit with only the lens exposed. The camera is a fixed, shock-mounted unit. There are no masts, arms, or tethers extending from the vehicle

f. State Sensing.

1) Sensing Vehicle State.

   Sensors used to monitor vehicle state are as follows:
   a) 3-axis gyro (Microstrain) – used to determine heading of the vehicle, acceleration in any axis and the Eulers / Quaterion matrices to determine the 6-degrees of freedom equations
   b) 1-axis gyro – specifically used for the GPS for heading sensing in odometry mode.
   c) Altitude sensor (Honeywell, SSEC) – highly accurate pressure transducer is used to measure altitude of the vehicle.
   d) Temperature sensors – used to monitor engine, oil and outside temperatures.

2) Vehicle Performance Monitoring and data use for decision-making.

   a) The vehicle uses real-time positioning combined with real-time computed routes - uses estimation for required fix times, and uses a 4-D (time/speed based) navigation solution to complete the race at an average speed.
   b) No later than two hours prior to race time, the vehicle will be assigned a 4-D navigation speed required to complete the race, based on the day prior's qualification run at California Speedway. This is the only parameter used to define the constraints on the vehicle during race time based on competition and our vehicles capability. Safeguards in the video system logic and other sensors will prevent the vehicle from exceeding safe speed parameters.

g. Localization.
1) Geolocation determination.

   a) Geolocation is determined primarily by a satellite-based differencial GPS Unit provided by Novatel. Secondary navigation means is through a WAAS-aided GPS, (u-Blox) with dead-reckoning capabilities. A high gain GPS antenna (27dB) is installed to help overcome weak reception.
   b) Cross-track error and position are based on the formulas (cross-dot product) for computation (projection of A-vector on to B-vector) in 3-dimension airspace.
   c) GPS unit accuracy, with WAAS, is less than 10 feet CEP, 95% of the time.
   d) The satellite-based DGPS accuracy is 20 to 30 cm CEP, 95% of the time.

2) GPS Outages.
   a) The GPS has an auto-calibrating dead-reckoning mode, where it uses a single axis gyro, and wheel proximity sensor. If GPS signal is lost, the GPS receiver reports dead-reckoning mode and continues outputting the GPS messages real-time as if it were receiving GPS updates with other sensors, accelerometers and heading sensors, providing inputs.

3) Route Boundary Detection.

a) The system will use a 2-sigma error buffer along any border (10 meters), except when path corridor is less then 2-sigma value, at which it will reduce the buffer boundary criteria.
b) For path corridor less then 2-sigma value, the video system will transition to a see-and-steer mode and search for a road, pathway, barriers, etc. to meet competition navigation requirements. When the video system has obtained edge-detection, the vehicle will 'center-up' on the pathway, road, etc.

h. Communications.

1) For testing purposes, a narrow band RS-232 data and cell phone with laptop will be used for telemetry. This system will be removed prior to the race.

2) Wireless signals: A 2-channel remote control receiver, to move the vehicle around before and after the race, will be installed. The transmitter will be removed from the vehicle prior to the race. The vehicle can be manually moved, if disabled during the race.

i. Autonomous Servicing
1) Not applicable for this design.

2) Checkpoint servicing is not required for this design.

j. Non-autonomous control. A 2-channel remote control receiver, to move the vehicle around before and after the race, will be installed. The transmitter will be removed from the vehicle prior to the race. The vehicle can be manually moved, if disabled during the race.

2. System Performance

a. Previous Tests. No previous tests have been run with the vehicle integrated. Prototyping of each component on the ATV with the hardware and limited software has been accomplished so far.

b. Planned Tests. There will be a series of build up tests (not including bench testing):
1) Basic vehicle movement, clearing the envelope with R/C as well as on board hardware/software safety features being tested (early November)
2) Basic guidance, navigation and controls (GNC) in autonomous mode (mid-November)
3) Vehicle stability and navigation: "I follow the leader" mode of testing—lead man-in-the-loop vehicle will have a GPS transmitting the position back every second to the DGC vehicle (end of November)
4) Drive by video system is currently in man-in-the-loop testing with positive results at speeds as high as 59 mph on-road (paved and unpaved). By mid-November the two systems will be coupled up and will combine steps 3 with 4 and reduce the spacing between transmission back to the DGC vehicle.
5) Fully integrated vehicle testing is scheduled for November.

3. Safety and Environmental Impact
   a. Vehicle top speed: Approximately 70 mph. The vehicle is expected to operate on straight and level terrain at near maximum speed if necessary to meet mandatory reporting points or finish time. Otherwise, the vehicle logic will command a more conservative speed allowing a time-margin for checkpoint arrival. Video processing limitations will require slower speeds during tight turns and uneven terrain. Actual speeds in tight turns is addressed in the proprietary annex.
   b. Maximum vehicle range: 350 miles
   c. Safety equipment:
      1) Fuel containment: Two metal tanks, one on each side of vehicle, will carry approximately 27 gallons. The fuel tanks **are** surrounded by a roll-cage from outside damage in the event the vehicle rolls.
      2) There is no automatic fire suppression or detection system on this vehicle.

      3) Audio and visual warning devices:

         a) Audio warning will use an SAE-approved devise.
         b) Visual warning devices are as follows:
            1. Yellow/Amber rotating light – An SAE approved amber light will be mounted on the vehicle. This light will illuminate 5-seconds prior to vehicle movement and remain on while the vehicle is in motion.
            2. Steady Green light – signifies the vehicle health status is good and the vehicle's safety pin is pulled, allowing vehicle movement.
            3. Steady Red light – signals the vehicle has a maintenance problem and is either in the process of resetting or shutting down.
            4. Brake lights (Red) – notifies chase the vehicle is in the process of decelerating (letting off the throttle and/or braking)
            5. Front lights (White) – provides illumination in low light conditions to enhance EO video system performance and provide vehicle visibility for safety (early morning or late evening).

   d. E-Stops.
      1) Emergency stop commands.

         a) One of four micro-controllers monitor the E-stop command for when the pin goes high. 1) It will in-turn broadcast a message to the PC, which will send a signal out to all the other micro-controllers commanding an E-stop maneuver. 2) The vehicle will retard the throttle to idle and begin to decelerate. 3) Depending on the speed of the vehicle, it will apply brakes (based on the speed and stability of the vehicle at the time). 4) Brakes will remain on and amber light and audio warning device will stop.

         b) For the second E-Stop (E-Kill), (second pin high), the vehicle will do an immediate disconnect of the ignition power source to the engine through a separate and dedicated relay. This will force the vehicle engine to stop. Testing has shown that shutting the fuel source off to the motor still allows it to run up to one and one half minutes, however, the circuit will also disconnect power from the fuel tank pumps. Battery power will have to be manually disconnected.

c) After permission for continuation (E-stop cleared or lost-of-communications reset), 1) the micro controller reads the DARPA-provided unit's output and signals the system that the E-stop is cleared, 2) the audio tone and amber light will restart for 5-seconds, 3) At 5-seconds, the brakes will release and the vehicle will continue the route.

d) If for some reason an inadvertent second E-stop command was sent, the vehicle can be restarted by re-inserting the safety pin to trigger the logic for the race vehicle to continue, 1) Turn battery switch back on (this will light the green start button), 2) Push the green start button to power up the electronics. 3) Confirm the remote control / autonomous switch is in autonomous mode, 4) Pull or re-insert and pull the safety pin and the green beacon light will reset (illuminate) and the vehicle will proceed using the procedures mentioned in the above paragraph.

2) Manual E-Stop switch(es). There will be two manual E-Stop switches mounted on the vehicle; one at the front of the vehicle and one at the rear. They are wired in parallel and are tied to the same functionality as RF E-Stop and E-Stop (E-Kill). The green light extinguishing is the only true means to signal the E-Stop mode has been accepted / processed by the software. The "safety pin" installed is the only way, hardware wise, to prevent vehicle or hardware movement as it directly disengages all electrical power to all the servos and electrical motors on the vehicle.

3) Neutral gear. The vehicle does have neutral setting, but with the engine off the vehicle can be moved in gear (torque converter transmission). A tow truck can easily lift the vehicle.

e. Radiators.
1) There are no radiating devices on the project (completely passive)
2) Hazard to eye or ear safety, and their OSHA classification level. (n/a)
3) Safety measures and/or procedures related to all radiators (n/a)

f. Environmental Impact.

1) The basic vehicle is a standard ATV with slight modifications to the structure. Rubber tires, small in size, should be minimal if any impact to the environment

2) Maximum physical dimensions (length, width, and height) and weight of the vehicle.

The vehicle is little more than 50 inches in width, but the length will extend to accommodate electronics. Vehicle height will be around 6 feet (72 inches) to accommodate video system electronics. The vehicle weight, with fuel, will be closer to 700 lbs. The vehicles maximum manufacturers gross weight is 1100 lbs.

3) Vehicle footprint and ground pressure.

   The area of the vehicle footprint is about 550 square inches. The maximum ground pressure is about 9.7 lbs per square inch.