Team Phantasm's Hoopla-OR-1 ("Hoopla Off Road One")

An entry in the 2004 Darpa Grand Challenge

Team Leader: Warren Williams

636-227-0935

Disclaimer: "The views, opinions, and/or findings contained in this paper are those of the participating team and should not be interpreted as representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense. DARPA and DoD cannot guarantee the accuracy or reliability of the information in this paper. The paper is published by DARPA as a service to those who seek additional technical information concerning the DARPA Grand Challenge of March 2004."

Team Description

We believe that our robot will be a task both difficult and rewarding, as well as exciting and will give us a sense that we would have a hand in helping to save the lives of some of our fighting men and women by removing them from the battle field.

Our team leader is a former Recon Marine with first person knowledge of the difficulties of the terrain weather as well as unplanned obstacles. Joining him is a computer programmer with more than 27 years of experience in a wide variety of systems, application, and device driver writing.

Also supporting our team's efforts are some outstanding sponsors who are providing the kind of real world support we will need in order to make this project into a reality. It definitely won't be easy but it will be doable.

1. System Description

a. Mobility.

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

Our Challenge Vehicle is a Kawasaki KFX ATV chassis.
Here is the web site with info on the vehicle:
http://www.kawasaki.com/index2.asp

It is a large all terrain vehicle (ATV) with four wheel drive and will use treads from Mattracks (website: http://www.mattracks.com). The tracks will be attached in the normal fashion that wheels are. (Please see the website for more detail.)

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

Steering will be the traditional method employed in all standard trucks and automobiles by changing the angle of the front treads as though they were wheels.

Braking is handled by standard disk brakes located on the wheel hubs.

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

All vehicle components will be actuated with pulse width modulation (PWM) devices that are controlling a motor controller attached to a drive motor which will turn the steering and activate the brakes.

Each PWM device (sensor and motor control) is controlled by a microcontroller that communicates with the main computer via a serial line that they share on a common network. (The microcontrollers network with each other and communicate with the main computer through a single serial line.)

b. Power.

i. What is the source of Challenge Vehicle power (e.g., internal combustion engine, batteries)

Our Challenge Vehicle will employ both an internal combustion engine and storage batteries.

The heart of the KFX700 V Force is the liquid-cooled, 697cc, four-stroke, 90-dgree V-twin engine matched to a performance-tuned Kawasaki Automatic Power Drive System (KAPS), Kawasaki's continuously variable automatic transmission.

We will be using a set of 2 - 12volt gel cell Hawkins batteries, 30 amps apiece. Conditioning will be done by the onboard microprocessor designed and built by Phantasm robotics. Extra power will be provided by standard and solar charging system. Our design is more compact and more efficient than anything ever used before. This too is new technology.

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

We're not sure of this yet, but our best guess is that the maximum will be somewhere around 500 Watts.

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

The vehicle will carry from 15 to 20 gallons of gasoline.

c. Processing.

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

There are two types of computer systems used in our Challenge Vehicle, Pentium class microcomputers and PIC size microcontrollers.

There will be from 4 to 12 microcontrollers and 1 or 2 Pentium class machines in the final design.

The microcontrollers will monitor all sensory devices except for the GPS as well as control the motor and braking activations, and the Pentium class machine(s) will execute all of the high level decision making functions including position determination, tracking, problem solving such as obstacle avoidance, and navigation.

The microcontrollers will be programmed in their native Forth language and the Pentium class machine(s) will be programmed in "**Hoopla**", a custom programming language with many features not found in other languages, and will be using Linux as a base operating system. (We want to avoid physical crashes, so we can't have our computers crashing!)

(**Hoopla** – Hierarchical **O**bject **O**riented **P**rogramming **La**nguage.)

Hoopla is a set of application-specific words (using **Forth** as a base language) that define an environment that can quickly react to interrupting conditions with predefined decision tables controlling how the vehicle should react to the interrupting conditions. Hoopla basically turns every sensory condition into an action similar to the way in which biological nervous systems react to stimulus such as a pin-prick or a bruising. Combining what might be called the "**Best of AI**", Hoopla is best described as (1) a set of sensory objects that combine (2) an Artificial Neural Network with (3) predefined methods that take the form of (4) a decision tree/expert system.

<u>DGC concerns:</u> The stated approach appears to combine neural nets, decision trees, and expert systems. These are powerful, effective methods, however, they depend significantly on how they are trained. Please describe how the stimulus-response pairs will be learned. How much training is needed? How will the system deal with stimuli it has never seen before?

This is a layered approach. The lowest layer involves the sensors and the Neural Network, primarily warning the Challenge Vehicle of obstacles to slow down for. Training of the NN doesn't require stimuli of **all** kinds, just like I don't need to be taught how to "duck" a bottle thrown at me, the very fact that my NN detects **something** coming at me fast is enough to react to it.

The very reason for taking a NN approach is to be able to react to **unknowns** that are **similar** to previously experienced knowns. We will be training the Vehicle to be wary of approaching objects and react accordingly.

ii. 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?

Each sensor is controlled by its own microcontroller, with programming specifically designed to interrupt the main computer(s) only if the microcontroller decides that an obstacle has been detected and will need to be avoided.

For the moment, we do not plan on having the system classify sensed objects other than as an obstruction. We prefer to keep things as simple as possible.

Our macro route planning begins with the Darpa “Route Layout Description” that we're given just before the competition starts. The main computer(s) will read it in, compile it (a process that compares the waypoints with our known built-in maps and decides the quickest way to route to the waypoints while remaining within the specified “lateral boundary”), and begin executing the plan. Obstacle avoidance will be an interrupt driven process that finds ways around or through the obstacle. As in any interrupted process, control returns to the original programming once the obstacle has been cleared.

Vehicle control is dispatched by the main computer(s) through another set of microcontrollers, which are also capable of their own form of interrupting the main computer(s) for servicing details. (Damage detection, low fuel, etc.)

d. Internal Databases.

i. 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?

We plan on making extensive use of the mapping data that is built in to the Garmin GPS V device. It is the only sensing device that will be directly interfaced into the main computer(s), and will form the backbone of our navigation system. The Garmin GPS V is the only commercial hand-held GPS device with built-in auto-routing that our main computer(s) will consult with. It may choose to not go the way of the Garmin's route, but the Garmin is well made and will reroute when it detects that we're not following its calculated route. We also plan on maintaining an internal representation of how far and in what direction we've gone so far.

e. Environment Sensing.

i. 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.

We will use a Radar system for long range sensing and sonar for short range. (See the Appendix below for product details.)

We will be using terrain following technology, this is a hybrid navigational system unlike anything used before, a composite of many systems working together. We will hard code the route and load the appropriate prepared routing data from the dem files received from our sponsors at the USGS. Having logged every conceivable route possible (up to the limits of our computer's memory) we will have a ready-made database for routing.

Then when race officials give us the route just before the race, we will select one of the many pre-traced routes. Now the robot has a known to work with. So we then need to sense only for real obsticals and avoid collisions with other competitors. The GPS will update our virtual world with the macro world to keep orientation. The radar will choose terrain features that are also pre determined and verify GPS data and USGS data and the pizeo electric gyros will give information as to pitch and yaw in real time. This will allow us to verify our posture, direction, location, and attitude while in motion. GPS is not the main source for navigation it is just a primary aid to the terrain mapping system with the radar and sonar to give avoidance and redundancy.

Other sensors are for system monitoring engine temp. speed, attitude pitch/yaw, as well as breaking input from darpa monitors for estop and hard estop.

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

We will use no masts, arms, or tethers. All our sensors are mounted directly on the vehicle, and will be protected by the frame. We don't want to risk damage to any of them should we unfortunately flip over or something.

f. State Sensing.

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

Fuel, temperature, electrical output, etc.

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

We want to keep things simple, and the only performance monitoring that we'll be doing is logging the progress via GPS NEMA information. We might log other things like temperature, fuel consumption rate, etc., for later analysis, but for now, the vehicle's performance will not be actively monitored as an input to route planning.

g. Localization.

i. How does the system determine its geolocation with respect to the challenge route?

By using a Garmin GPS V device for satellite navigation.

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

Two methods of navigation are incorporated in our design: GPS and vectored tracking. Unfortunately, vectored tracking will accumulate error at an alarming rate, but we're hoping that the GPS outages won't be so severe that we will have to rely on vectored tracking.

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

We will try to stay in the middle per say, combining GPS and terrain feature following in order to stay in bounds.

<u>DGC concerns:</u> The stated approach is to manually identify terrain features in advance of the event, and then to use the on-board radar and sonar to find those features during the event. This seems difficult, but doable. However, once the features have been found by on-board processing, how does that feature position (for example, radar pixel (r, c)) determine the vehicle position with respect to the route boundaries? Please demonstrate that this will be sufficiently accurate to keep the vehicle within the course boundaries, which may be as narrow as 10 feet. Also, please clarify how the method will "verify with other onboard systems to get exact location."

Again, this is a matter of layers. The topmost processing layer is the terrain feature mapping system, which subsumes **all other** sensory data and processing. Staying within the boundaries is primarily the responsibility of it. Although both approaches are running at the same time, position determination by terrain identification method **overrules** the GPS (when it is "locked"). We expect conflicts between the systems, and defer to the terrain feature mapping.

We believe that our approach is a unique one that has the advantage of having extremely detailed map data from one of our sponsors, the **USGS**. The challenge, of course, is to be able to recognize those unique terrain features considering the fact that things change, and there will no doubt be missing objects, extra objects, and surprises of all kinds. We don't claim that the approach is perfect, but we believe it is a worthy enhancement and backup to the standard GPS way of modern robotic navigation.

h. Communications.

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

The main control program of our challenge vehicle is a webserver that runs background tasks. The background tasks make up the main navigation and decision making functionality of the vehicle. The webserver will respond to wireless HTTP 1.1 requests from a nearby PC with a wireless card in it.

This makes our design simple and still allows remote control and telemetry when necessary. (During development and testing, **NOT** during the actual challenge run.

We do not plan on making any refueling stops, we're looking to make the trip non-stop.

ii. What wireless signals will the Challenge Vehicle receive?

The initial routing data that we receive just prior to the beginning of the race. Again, this will be from a laptop computer with a wireless card running a standard web browser, and sending standard HTTP 1.1 browser requests to the webserver running on the Challenge Vehicle's main computer(s).

i. Autonomous Servicing.

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

No, we don't plan on any refueling or servicing during the race.

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

No, we don't plan on any refueling or servicing during the race.

j. 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.

As described in h.ii., above, we plan on controlling it locally by a low power, short range wireless connection to the main computer(s). The wireless card on the challenge vehicle will remain on, monitoring any SSID-valid browser requests that it receives, so therefore, it will be able to pick up and respond to commands issued by the Darpa judges at any checkpoint or at the finish of the race, or at any point between so long as they are within the limited range of the 802.11b signal, and are using the correct WEP keys.

2. System Performance

a. Previous Tests. What tests have already been conducted with the Challenge Vehicle or key components? What are the results?

The key components that have been tested so far include the microcontrollers, the main computer(s) web server software, the GPS device, and the various IR and Sonar sensors. All were performing as expected and are encouraging to us.

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

When our Challenge Vehicle is assembled, we plan on doing several road tests under close control with possible some additional safety equipment added.

2. Safety and Environmental Impact

a. What is the top speed of the vehicle?

The top speed will be from 50 to 60 MPH.

b. What is the maximum range of the vehicle?

Our Challenge Vehicle's maximum range should be around 300 miles.

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

i. Fuel containment.

We will employ fuel bladders, not hard tanks. This will help with roll overs and minimize the danger of punctures.

ii. Fire suppression.

There will be an onboard fire extinguisher for fire hazards in or around the fuel tank and/or engine. It will be triggered by remote or by the main computers on-board safety system manager.

iii. Audio and visual warning devices.

The vehicle will be decorated in an eye-catching way to assist in warning the public of the danger. We will also have flashing lights and a loud horn as well.

d. E-Stops.

i. 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.

We will have a fail safe state for the stop condition. Actions triggered will include throttle off, breaking applied, neutral gear position. We expect that this action will happen within .50 seconds and the vehicle will stay in a state of null motion for 3 minutes. If a command is not received to shut down, the vehicle will continue after this. If the signal is received the vehicle will lock the breaks and shut off the engine. No restart can be accomplished if this occurs. This is the hard stop.

The soft stop It will be triggered by the main computer if we encounter a condition that is determined by the system to be an emergency. It will apply the clutch and the null throttle and slight breaking as needs, depending on the distance of the probable area or obstacle.

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

The manual estop will be the main break switch that will prevent the unit from receiving any signals and will lock down the system for a hard break awaiting "replacement of the key" if you will. It will stay ready for the start signal from our main processor. This is a real break in the system operation. The vehicle can in no way operate with out this device plugged in. No arrant signal can cause it to move.

iii. 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?

We will be using the vehicle shift switch. The switch is electronic so it's easy to place in neutral, the transmission is automatic, so it is not a mechanical issue as a "manual" transmission would be. The vehicle can be towed and/or trailered.

e. Radiators.

i. 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.)

Our radar is a 77 ghz forward looking radar. We provide a ttl logic controlled feature when the radar is disabled. When the vehicle stops, no emissions will occur. It only operates while the vehicle is in motion. This is controlled by digital means. Power output to the antenna is about 10mw. The antenna gain is about is 28 db about 38 dbm for erp.

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

We will employ no hazardous lasers or sound emitting devices other than the warning horn.

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

See section i above.

f. Environmental Impact.

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

None that we know of. This vehicle is an ATV. Small, light weight, and fast, but not a large foot print or so heavy that may cause damage to the dirt.

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

The vehicle is about 6 feet long, 4 feet wide, and 3 feet tall. It weighs about 400 lbs.

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

The area is about 8 square feet with four treads: one set on the front wheels and one set on the rear wheels. This means about 50 pounds per square feet when the vehicle is standing still.

Appendix

RADAR:

Epsilon Lambda Electronics

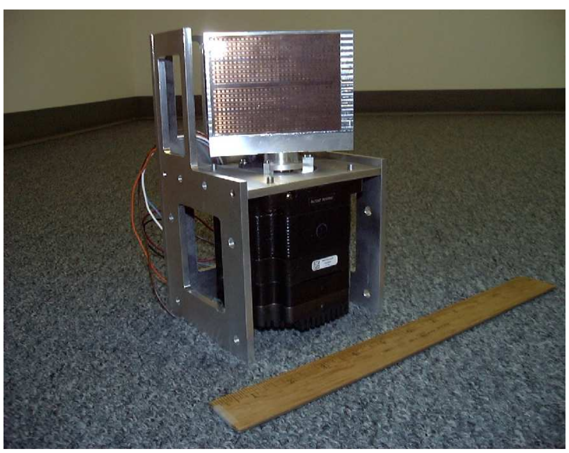
Since 1974

Celebrating 29 Years as the Millimeter Wave Industry Technology Leader

---

Epsilon Lambda Electronics
Introduces

Three Dimensional Tracking Obstacle Detection Radar Sensor at 77 GHz



Model # ELSC71-1A

The first millimeter wave obstacle detection sensor with three-dimensional target tracking capability (range, azimuth angle, and elevation angle)

Most obstacle detection sensors only offer two-dimensional target information. None of the current products offer the high level of performance required for reliable obstacle detection or collision warning. The Model ELSC71-1A is the first sensor to combine the following features:

- FM-CW Ranging Radar – Millimeter Wavelength (High Resolution)
- High Gain Antenna with range up to 110 meters (compact car)
- 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
- Compact Size, Rugged Construction

- Code loaded into host vehicle computer

This 3D radar sensor is suitable for robotic vehicles, off-road vehicles, military convoys, etc. Obstacle data reported includes range; azimuth angle, elevation angle, relative velocity, and signal return amplitude. Epsilon Lambda Electronics will also build 2D and 3D sensors to preferred customer specifications.

Model ELSC71-1A Specifications

Transmitter Power	+10 dBm
Center Frequency	76.5 ± 0.2 GHz
Vehicle Speed Max	45 mph
Number of obstacles tracked	8 in beam width
Temperature Range	-20 to + 85 degree C
Antenna Gain	> 27 dB
Azimuth FOV	± 20 (wide), ±8 (narrow)
Azimuth Beam Angle	3 degree
Azimuth Angle Resolution	1.8 degree
Elevation Beam Angle	7.6 degree
Elevation Angle Accuracy	1.0 degree
Polarization	Linear
Operating Range	30 meters (wide), 110 meters (narrow)
Obstacle List Update Rate	100 ms
Range Resolution	1.0 meter
DC Power (*75VDC Supply Optional)	+ 12VDC (3A) ; -12VDC (100MA) + 75VDC (3A); 5VDC(1A)
Weight	3.5 Kg
I/O Board Type	PCI-6110S or PCI-6111S (National Instruments)
I/O Connection	ELE Cable

SONAR:

Developers Kit
Our most complete kit. The quickest solution for product development. This kit includes one each of the 7000, 9000 and 600 Series Environmental transducers, an Intel 80C196 microprocessor, a liquid crystal display (LCD), and a technical manual. Configuration software, running on your IBM PC compatatible, allows you to reprogram performance characteristics such as transmit frequency, pulse width, blanking time, amplifier gain etc.

Specifications: Range 2.5 cm to 15.2 m, resolution with 1% of the reading (over the range), Input/Output RS232 port, analog output, pulse-width modulated, and externally triggered input.