# Oregon WAVE Technical Report

## DARPA Grand Challenge


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## Abstract

OregonWAVE "Runner" is built on the platform of a Mini Baja racer. GPS/INS measures the vehicle's state, and a Laser Measurement Unit collects terrain data. The processing is done on a MicroBlaze microprocessor instantiated on a Xilinx Spartan III FPGA. A good path is determined based on the race course, vehicle state, and the terrain map. A fuzzy logic controller ensures that the vehicle follows the desired path by outputting appropriate commands to the throttle, steering and brake servos. Extensive testing was completed to ensure that OregonWAVE "Runner" with perform accurately and reliably at the Darpa Grand Challenge 2005.


## Introduction

OregonWAVE is an acronym for Oregon Willamette Autonomous Vehicle Enterprise and is an autonomous vehicles development team based out of Oregon State University. The goal of the team is to field a vehicle in the 2005 DARPA Grand Challenge field trials. The team is composed of university and private companies and individuals collaborating to this goal.

## 1. Vehicle Description

The OSU award winning Mini Baja off-road racer has been used as the platform for the WAVE autonomous vehicle. OSU competes in the SAE Mini Baja race every year, and each year a new Mini Baja racer is built by OSU students. The OregonWave autonomous racer is the retired Mini Baja racer from 2003. The racer is an open vehicle with a steel frame; it is smaller than a street car, measuring about 4 feet wide, 5 feet long and 5 feet high, and about 500 pounds. The racer was chosen because of its availability and its unique characteristics which are well suited to the Challenge. The racer exhibits very impressive off-road abilities in order to compete at the Mini-Baja race, including being able to drive over large boulders and roll without damage. The racer can turn tight corners and is able to easily pass over rough terrain.

A few modifications have been made on the racer in order to compete in the Challenge. The seat and steering wheel were removed from the racer. The racer's engine was limited by SAE rules, and has been replaced by a 13 horsepower engine with a higher top speed. A larger fuel tank has been added to supplement the existing fuel tank, so that the racer will have enough fuel to finish the race. The Mini Baja racer is an open vehicle, so considerations were made to ensure that all equipment was waterproof. An electronics box was built and added to the racer to house all of the various processing elements and other items that need to be enclosed against the possibility of rain. Certain repair type modifications were necessary to ensure that the racer was in top shape to compete in the Challenge.

## 2. Autonomous Operations

### 2.1. Processing

The main processing element is a soft microcontroller called a MicroBlaze instantiated on a Xilinx Spartan III FPGA. The MicroBlaze is designed to be very flexible; the user has control over a number of features that impact performance. The necessary performance for an application can be obtained at the lowest possible cost. For the autonomous vehicle application, a flexible microcontroller was very suitable because there was no need for a large operating system compared to a PC. The Spartan III offers a wide range of I/O options which is vital to the application so that all of the vehicle level and environmental sensor data can be directed to the appropriate processing tasks.

The main processing elements are DRIVER, TERRAIN, and GOAL_LOGIC and are kept as separate threads on the MicroBlaze processor. DRIVER is concerned with actually driving the vehicle. The DRIVER program is given a command that consists of where it is desired that the vehicle go, in the form of a speed correction and a heading correction. Using an estimate about how the vehicle will react, the DRIVER computes and outputs commands in the form of pulses to the servos that control the throttle, steering and brake. TERRAIN inputs all the sensor data and builds a terrain map. The TERRAIN program uses all the processed data from the LMS unit, and also uses sensing data from the GPS/INS including latitude, longitude, attitude and speed to determine where the racer is and where to place obstacles on the terrain map. The TERRAIN program is also responsible for telling the DRIVER program what speed correction and heading correction is necessary to move along the desired path. The GOAL_LOGIC program interacts with the Darpa issued E-Stop, is aware of the GPS waypoints and the course boundaries, and uses information from the terrain map to plan a path for the vehicle. The GOAL_LOGIC program also gets sensing information directly from the GPS/INS sensor so that the position of the vehicle is taken into consideration. Any errors in execution of the path will not escalate, because GOAL_LOGIC is using current position information from the sensors and is updating the path based on actual position instead of assumed position.

Figure 1 shows a functional block diagram of the processing architecture on OregonWAVE "Runner". Sensor data is input to the processing elements TERRAIN and GOAL_LOGIC. Vehicle level sensor data is input to TERRAIN and GOAL_LOGIC, environmental data is input to TERRAIN. Navigation is handled by the program DRIVER which is directly coupled to the actuation in the form of throttle, steering and brake. The main challenge faced in realization of the system was reliable communication between the processing elements and between the sensors and processing elements. The communication issues were almost entirely solved by switching to the MicroBlaze processor instantiated on a Xilinx Spartan III FPGA. Although multiple processors would help ensure that each processing task was kept separate and did not impact the speed and reliability of other processing tasks, communication between multiple microprocessors was unreliable. Using just one processor and an integrated network simplified communication, while tasks could still be kept separated by running them on separate threads.

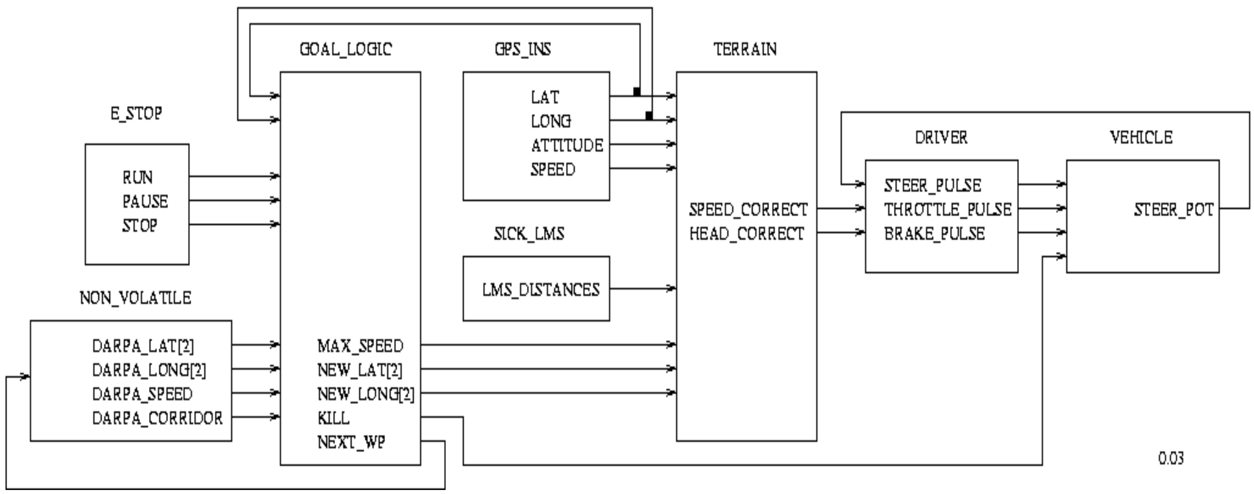


Figure 1. Block diagram of the system architecture implemented on the OregonWAVE autonomous vehicle “Runner”.

## 2.2. Localization

For localization, OregonWAVE “Runner” was using two Garmin GPS16-A units combined with a Microbotics MIDG II GPS/INS unit. The GPS units each have 3-5 meter accuracy, averaging two units significantly improves Runner’s ability to waypoint follow. The Microbotics GPS/INS unit increases overall accuracy and reduces noise by filtering. The unit has dead reckoning capability for times when there is no GPS reception. With the Microbotics GPS/INS unit, the Garmin sensors were no longer needed because the GPS/INS gives the position of the vehicle with much greater accuracy. Position accuracy continually decreases as GPS reception is unavailable, even with dead reckoning, but can be improved by adding vehicle level sensors such as track over ground and wheel speed.

Map data is not an integral part of OregonWAVE Runner’s navigation system.

## 2.3. Sensing

A LMS unit is located on the front of the vehicle. It is positioned so that the frame of the vehicle will not interfere in the 180º range of the sensor. The LMS unit has a range of 80 m, an angular resolution of 0.25 degrees, and measurement resolution of 10mm. The LMS unit will be fixed straight ahead most of the time, but will also be able to pan up and down if more detailed information is needed about the environment. Panning up and down will collect more information than just a single pass would allow. The LMS is shielded from the sun by a matte black visor mounted above the unit. Vibration, rain and dust are filtered out of the data in the software. The GPS/INS unit is mounted close to the centerline of the vehicle, so that calibration of roll, pitch and yaw is the most accurate.

Laser range data is collected from the LMS and digitally noise filtered. Each set of range data is drawn onto a 3D world map where the location for the data is calculated based on which direction the LMS was facing when the data was collected. The position of the vehicle from the GPS/INS sensors at the time that the LMS data was collected is also used to place the data on the terrain map. Disparate data is fused using averaging.

Internal sensors used to sense the vehicle state are GPS/INS, steering potentiometer, RPM sensor, Throttle actuator position, LMS position, Gear box actuator position, and Choke position.

Waypoint following is done by the fuzzy logic controller. The fuzzy logic controller outputs a steering command based on a heading angle correction to the next waypoint. Obstacle detection is done by interpreting the data from the Laser Range Measurement Unit. When an obstacle is detected it is placed on the terrain map, and the terrain map is used to determine a good path to the next waypoint. The waypoint follower is adapted to path planning by dividing the path up into a sequence of waypoints closer together. Collisions are avoided by adapting the steering, or throttling down in most cases. Braking is used only in situations when it is necessary to stop the car quickly.

## 2.4. Vehicle Control

The goal of the OregonWAVE "Runner" is to control the vehicle by a general approach that can handle all possible non-ideal situations equally well. If there is a problem, the vehicle slows down, or comes to a complete stop, and reevaluates all the data to make a more sophisticated decision not normally possible due to the time constraints of high speed. The lidar is mounted on a swivel so that in an extreme situation the lidar can scan a situation more thoroughly in order to get a very good representation of the environment. Also, the path is being updated all the time, so if there is an obstacle in the path or there is a problem such as a missed waypoint or the car is outside the boundaries, an updated path will take care of the problem.

The mini-baja platform is a well suited to making sharp turns and starting on hills. Brakes have been added to the servo controlled throttle so that the vehicle can slow down quickly. The route boundaries are taken into account on the environment map and the path is planned to stay within the route boundaries. The turning radius of the car is known and planned for while creating the vehicle's path.

Sensing and navigation information are integrated by adding all data to the terrain map. The fuzzy logic waypoint following controller is using the GPS/INS data to follow waypoints all the time. Environment data is collected from the Lidar unit and added to the terrain map. The path is created using the waypoints and the terrain map. The path is converted to sub waypoints and is followed by the waypoint follower.

When the car is not in autonomous mode, a three-channel remote control is used. The remote control can be used for steering, throttle, brake and kill or it can be used along with autonomous control. It is convenient for testing to have autonomous steering and remote control throttle and kill.

## 2.5. System Tests

OregonWAVE's testing strategy is to take the vehicle out as often as possible. There is a field within a few minutes of the lab, which allows the vehicle to be taken out and tested when each new component is added and whenever major code changes are made. Reliability is tested by taking the vehicle out for long periods of time. Several other locations that are close by are used for more intensive obstacle avoidance and terrain navigation. As the vehicle technology progressed, it was necessary to find field sites where the limits of the vehicle could be tested. These sites were picked to be long and complex where we could throw a diverse range of challenges at the car.

The tests were very good for determining component reliability. For the most part the vehicle performed as expected. It was determined from the testing that steering turning rate, and throttle deceleration rate were important factors to take into consideration. There were a few components that were not robust enough to withstand the demands of the testing and were replaced with more heavy duty components.