DARPA GRAND CHALLENGE 2005
TECHNICAL PAPER

Team UnderDawg

www.TeamUnderDawg.com
Grand Challenge 2005

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Introduction

Team Underdawg, led by Jonathan Stark, is composed of San Francisco Bay Area software engineers, hardware engineers, designers, and mechanics. Every person on our team is an expert in his or her field. We think fast, act fast, and make things happen any way we can. This is our team's first Grand Challenge Event.

1. Vehicle Description

1.1. The vehicle is a 1989 Jeep Cherokee. It was chosen initially for its low cost ($500), its four-wheel drive capability, and Jonathan's familiarity with Jeeps. The gasoline-powered engine and transmission are completely stock. A cage made of square tubular steel was welded into the inside of the vehicle for reinforcement and equipment mounting. A smaller steel frame was welded onto that through the roof for securely mounting the external instruments.

1.2. The vehicle is equipped with larger off-road tires and a small lift for increased ground clearance. We estimate that the stock fuel tank will be sufficient for our entry into the Challenge.

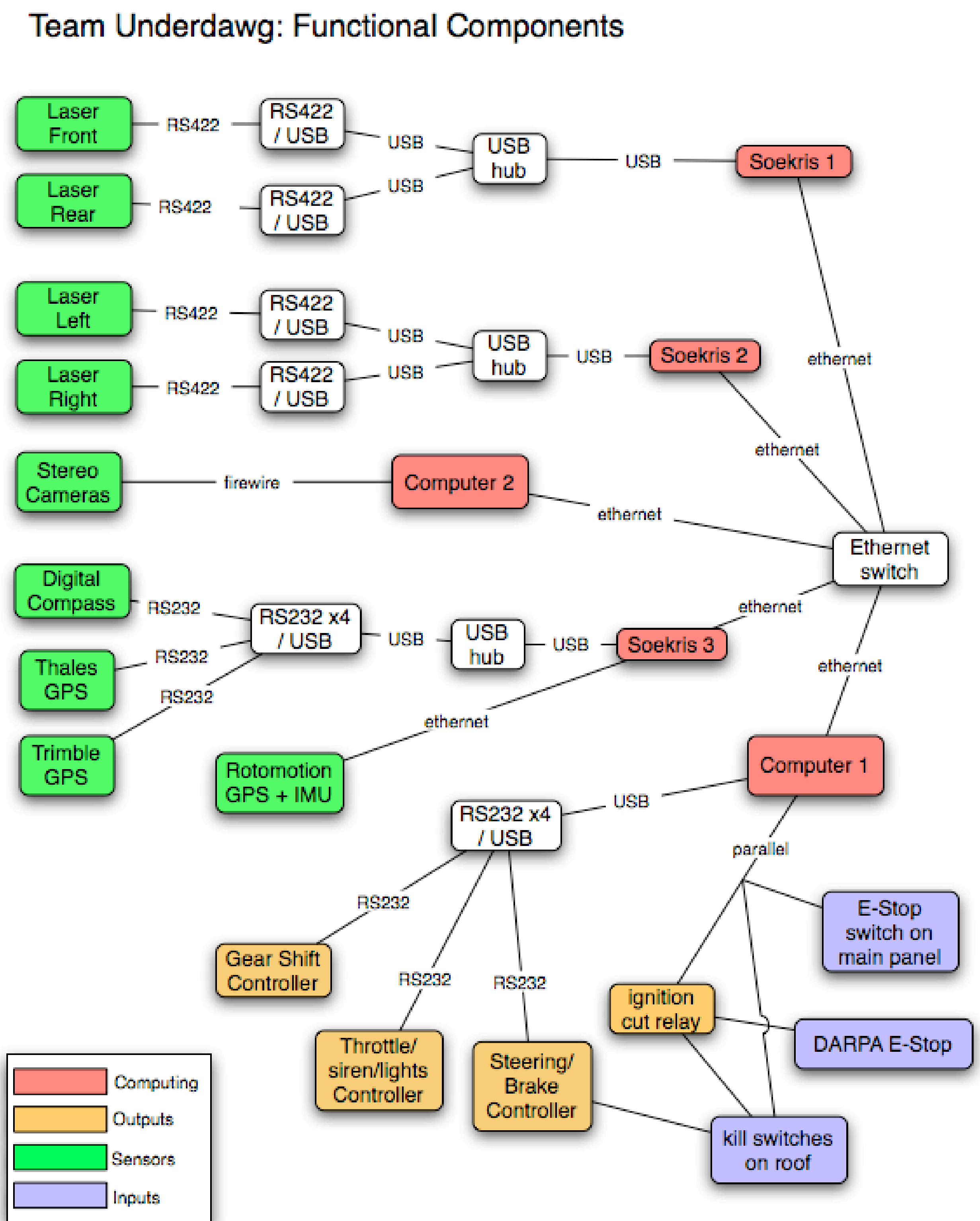
(Vehicle shown above does not include many recent modifications)

2. Autonomous Operations

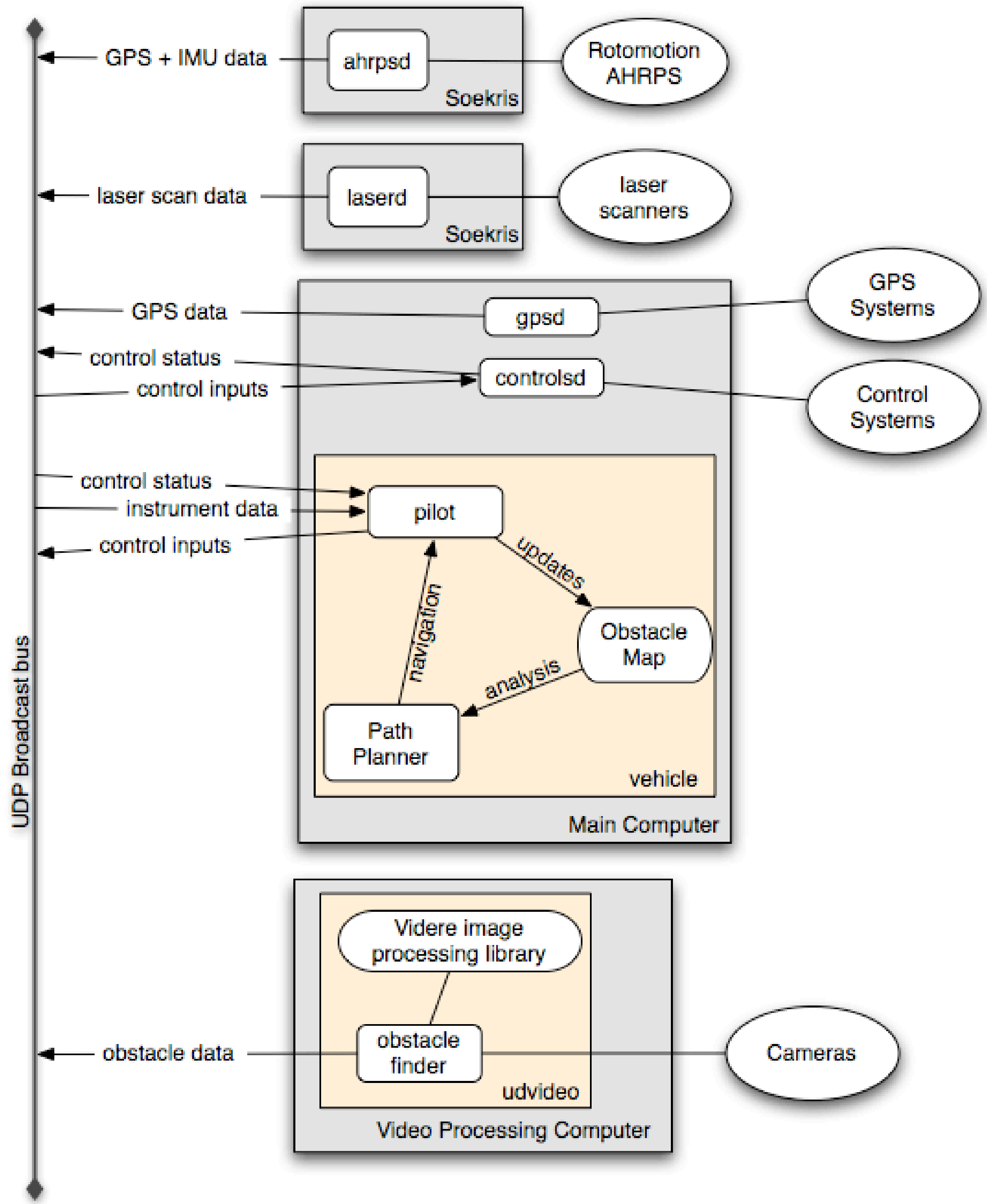
2.1. Processing

2.1.1. Computing systems include two Intel Pentium-M systems in a ruggedized Mini-ITX configuration. One system handles sensor data aggregation, navigation, and control systems input. The other system handles video processing duties. These computers are mounted on vibration-isolating mounts, and the hard drives are designed to operate in high vibration environments. Processing of USB data from laser scanners is handled by three Soekris Net4801 Geode-based computers. The operating system on all computers is Linux, from the Fedora Core 3 distribution.

2.1.2. Diagrams:


Team Underdawg: Functional Components
Laser Front
RS422
RS422 / USB
USB
USB hub
USB
Soekris 1
Laser Rear
RS422
RS422 / USB
USB
Laser Left
RS422
RS422 / USB
USB
USB hub
USB
Soekris 2
ethernet
Laser Right
RS422
RS422 / USB
USB
ethernet
Stereo Cameras
firewire
Computer 2
ethernet
Ethernet switch
Digital Compass
RS232
RS232 x4 / USB
USB
USB hub
USB
Soekris 3
ethernet
Thales GPS
RS232
RS232
ethernet
ethernet
Trimble GPS
Rotomotion GPS + IMU
Computer 1
USB
RS232 x4 / USB
parallel
RS232
E-Stop switch on main panel
Gear Shift Controller
RS232
RS232
ignition cut relay
DARPA E-Stop
Throttle/ siren/lights Controller
Steering/ Brake Controller
kill switches on roof
Computing
Outputs
Sensors
Inputs

Team Underdawg: Software and Network Architecture



2.1.3. Very little formal design was done on the overall software architecture. Since each module of the system communicates completely via UDP broadcast packets, different programmers with different design philosophies can produce code very quickly. Naturally there is a tradeoff between development speed and maintainability. In all areas of this system, we have decisively chosen to optimize for development speed.

2.2. Localization

2.2.1. The system utilizes several position, heading, and inertial measurement systems:

- Thales Navigation DG16 GPS system - 12 L1 carrier phase GPS channels and 2 SBAS channels.
- Trimble AgGPS 252 GPS system – 12 L1 and L2 carrier phase GPS channels and the ability to receive various correction signals, most notably OmniStar HP.
- Rotomotion AHPRS - Altitude Heading Position Reference System. This unit combines a GPS, a 3-axis magnetometer, 6-axis accelerometer, and a 6-axis gyroscope.
- TrueNorth TNT Revolution 2X – 3-axis magnetometer.

The primary method of navigation is GPS. There are three total GPS receivers in the system, all of which appear to have different performance under different circumstances. Whenever possible, we make use of WAAS or other freely available correction signals to compensate for atmospheric error. The Trimble GPS unit has an OmniStar HP receiver that provides additional correction. During a GPS outage the Rotomotion AHPRS will continue to provide position updates based on magnetometer, accelerometer, and gyroscope data.

2.2.2. Map data is not particularly important to our system. We have utilized freely available map data in the development and debugging process. Our principal finding in this area was that freely available map data is not very inaccurate.

2.3. Sensing

2.3.1. There are three SICK laser scanners on the roof of the vehicle near the front. Each scanner is mounted inside of a protective case with a sun shield and a rolling film screen. The scanners’ aim is adjustable, and we regularly tune these settings to determine the optimal position. There is also a rear-facing laser scanner, mounted on the roof. These scanners sweep a 100 degree arc, and are typically aimed between 5 and 20 meters away from vehicle.

A Stereo camera array from Videre Design is mounted on the roof inside one of the scanner boxes. These cameras can see up to a 40 meter distance from the vehicle with diminishing accuracy relative to object distance. The precise aiming point of the cameras is still being tuned.

2.3.2. Data from the sensors is fitted to a map of the surrounding environment using data from the localization systems. As the sensor system discovers terrain features such as drivable surfaces, obstacles, etc. the environment map is updated. In this manner, both the sensor and the localization systems can be modified and improved with minimal integration between other systems.

2.3.3. Vehicle speed, acceleration, position, and orientation are handled by the various localization system components. Additionally the steering and brake systems have a closed loop controller that makes current steering and brake position values available. There are currently no other sensors for vehicle state. This is largely due to our budget-driven selection of an older vehicle which unfortunately was not equipped with many sensors from the factory. Thus far our performance has been acceptable without these additional sensors.

2.3.4. Our "pilot" software is responsible for aggregating sensor data as well as communicating with the vehicle controls. Pilot updates the common environment map, and another "path planner" process evaluates this data to find roads, follow waypoints, and detect obstacles. The Path Planner indicates a desired course to the Pilot which attempts to follow it.

Pilot uses the UDP broadcast bus to interact with the steering, brake, accelerator, and gear selector controls. These 4 systems are controlled by various dedicated microcontroller boards that were custom-fabricated by our team. Since our steering and braking control systems were added in parallel to the vehicle's factory systems, no good models of their performance were available. Thus we performed an iterative tuning process that yielded the model which has been incorporated into Pilot.

See diagram above for an illustration of how these systems interact.

2.4. Vehicle Control

2.4.1. Should Path Planner detect a missed waypoint, it will endeavor to turn around as quickly as possible to hit this point. If the course is such that turning around is impossible, we will continue on to the next waypoint. No attempt will be made to use reverse to collect a missed waypoint, nor will we back up if we detect that we are outside the LBO. Due to the difficulty of navigating obstacles and terrain from the rear of the vehicle, reverse gear is used exclusively for three-point turns and for trying to get un-stuck.

Pilot can detect if the vehicle is stuck. If so, it will repeatedly drive in reverse gear and then forward gear until more forward progress is made. Additionally steering will be added during these cycles to attempt to gain more traction. This cycle will continue forever until forward progress is made or the vehicle runs out of fuel. There is currently no provision for marking the area in which we were stuck as an obstacle.

If an obstacle is detected by the Path Planner, a new course will be selected that avoids this obstacle. Primarily the Path Planner analyzes the road surface data on either side of the obstacle and then weighs the predicted LBO positioning to determine the best avoidance strategy.

2.4.2. Our vehicle's speed control system uses the throttle and the brakes to keep the vehicle's speed within a selected range. Once the desired speed range is selected, either brakes or throttle will be used depending on the current speed. The desired speed is adjusted for many factors including road surface, hills, and obstacles.

To manage starting or stopping on a hill, we keep the brakes on until normal navigation begins. The throttle is ramped up just before the brakes are released, but there may be a brief period where we roll downhill unintentionally as we transition from Pause to Run states.

If a turn is too sharp to negotiate without exceeding the LBO, we will attempt a three-point turn maneuver. If more points are required, we will likely then exceed the LBO.

2.4.3. An important design goal of our vehicle was that a person could drive it normally if the automation systems were disabled. All controls are still accessible to a human driver, though the feel is substantially different from stock. The factory steering wheel has been replaced by a wheel connected to a hydrostatic steering system. More wheel input is needed in one direction than the other, which is odd, but most drivers adapt quickly. The brake pedal is still used to actuate the brakes, but the vacuum assist has been disabled. Thus, a human driver usually requires both feet on the pedal and a lot of force to stop the vehicle. The accelerator operates normally. The automatic gear selector system attaches to the shift lever with a pin. When a human drives the vehicle, the pin is removed.

2.5. System Tests

2.5.1. Our testing strategy is very informal. When new components need testing, the entire vehicle is run to test them. If any defects are discovered while testing, they are added to the bug database. Our components are fairly rugged, but we have no formal methodology for determining how long we expect them to last. It is our belief that component failure will not limit our competition in the Grand Challenge.

We have access to a test facility in Northern California that has dusty mountain roads, steep hills, dry and flowing creek beds, and a variety of vegetation. We believe that this facility represents a reasonable version of the final Challenge site.

2.5.2. Among the key challenges are:

- GPS accuracy – While the relative accuracy of our GPS systems is very high, the absolute accuracy is vexingly low. We have attempted to compensate for this by using very high end GPS system with satellite-based correction signals.
- Laser scanner limitations – In very dusty conditions the accuracy of the laser scanners diminishes quickly. Additionally if the sun is near the horizon

shining directly into the scanner we lose accuracy. We have attempted to compensate for dust by using scanners capable of operating in fog and by building a rolling screen to keep the laser's view clear.

- Water detection – to the laser scanners and cameras, smooth water looks like a very desirable driving surface. We do not yet have a method for avoiding water.