A Technical Report on

TAILGATOR

Submitted to:

William G. Agnew

11th Annual Intelligent Ground Vehicle Competition

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Center for Intelligent Machines and Robotics (CIMAR)

UNIVERSITY OF FLORIDA

Faculty Advisor's Statement

The work that the AUVSI Ground Vehicle Competition student team performed with regards to design and implementation was significant. It is equivalent to work that is typically awarded credit in the University of Florida Mechanical Engineering senior design course.

Dr. Carl Crane

Faculty Advisor, Center for Intelligent Machines and Robotics, University of Florida

Introduction

The goal of this design project was to develop an unmanned ground vehicle (UGV) to compete in the Intelligent Ground Vehicle Competition hosted by AUVSI. The University of Florida's vehicle is a unique approach to this challenge incorporating emerging technologies and standards.

Design Process

The University of Florida employed a slightly modified version of the design process outlined in *Fundamentals of Engineering Design (Barry Hyman*). The seven step design process is shown as follows:

1. Recognize the need.
2. Develop detailed problem statement.
3. Gather background information.
4. Generate concepts.
5. Select best concept.
6. Perform detailed design and analysis.
7. Develop prototype and perform testing.

The UF design team recognized the need to develop an unmanned vehicle to compete in the AUVSI ground competition. The team developed a detailed description of the problem clearly stating all the specific design parameters that were identified. Research was performed to discover all relevant background information such as the related work of others, as well as patent search results. Concepts were then generated and the ideas developed as potential ways to solve the design problem. Sketches, diagrams and drawings were particularly useful in explaining the different concepts. The "best" concepts were then selected based on sound reasoning and engineering criteria. The selected "best" concepts were then developed and presented along with results of analysis that were conducted. Cost information related to prototype construction was also presented. A prototype was developed and the results of testing including any deficiencies in the design and improvements that were made were presented. Details of these design process steps are presented in the following sections of this report.

Problem Statement

The TailGator platform is built to compete in the Intelligent Ground Vehicle Competition. The requirements of a vehicle designed to compete in this competition are complex and lengthy. Primarily TailGator must be capable of competing in the three challenges presented by the competition, the Autonomous Challenge, the Navigation Challenge, and the Follow-the-Leader competition. TailGator must be able to drive autonomously while carrying a 20 pound payload. For the Autonomous Challenge it must drive between two white lines while the Navigation Challenge requires the ability to navigate from waypoint to waypoint. Both challenges require the vehicle to detect and avoid spatial obstacles. The specific system requirements are explicitly stated on the competition web site, http://www.igvc.org and are not repeated here.

The design team also imposed other design requirements outside the scope of the competition. The vehicle was required to be compliant with the Joint Architecture for Unmanned Systems (JAUS) reference architecture in order to be a base platform for future JAUS development work.

Background Information

The University of Florida's TailGator was designed and built to be compatible with the JAUS reference architecture. The selection and application of JAUS to the TailGator project was deemed significant as JAUS is emerging as the DOD standard architecture for all unmanned systems and is currently part of the Operational Requirements Document for the Future Combat System. The purpose of JAUS is to provide interoperability between various unmanned systems and subsystems for both military and commercial applications. JAUS seeks to achieve this through the development of functionally cohesive building blocks called components whose interface messages are clearly defined.

In the language of JAUS, a number of terms are used to delineate position within the overall hierarchy of the system. These terms describe the different levels of the architecture and often imply an internal hierarchical sub-grouping. These terms are as follows: System, Sub-System, Node, and Component. A system consists of one or more sub-systems. A sub-system consists of one or more nodes and is usually thought of as a single vehicle. A node consists of one or more components and is typically thought of as a single computing device. A component represents the lowest level of decomposition within the JAUS reference architecture and performs a specific function. An important part of JAUS is the specification of the messaging or interfaces between components. The interface defines what information goes in and what information comes out of the component, thereby indirectly constraining the function of the component. The interface does not and should not specify how the function is carried out. This leaves the implementation details to the various systems engineers.

Implementing JAUS on the TailGator greatly streamlined the design and prototype development with regards to the integration of all subsystems. In addition, future upgrades can be made to the system on a modular basis.

TailGator employs a message routing system built to the JAUS specification and makes use of four components and their associated messages that are defined in Version 3.0 of the JAUS reference architecture. These components are listed as follows:

1. Sub-System Commander
2. Global Pose Sensor
3. Velocity State Sensor
4. Primitive Driver

These components shall be discussed in more detail later in this report.

Conceptual Design & Selection of Design Concepts

Base Vehicle

The design team first set out to select a base platform for use as a host vehicle for this competition. The team had a number of choices including commercially available platforms and custom built platforms. Due to constraints associated with preparing for the competition, the team's choice came down to primarily a choice between two commercially available platforms, i.e. a 'power wheels' based platform and the Suzuki Mini-Quad. Table 1 lists the advantages and disadvantages of each vehicle as determined by the design group.

Table 1 - Base vehicle comparison chart

Mini-Quad	Power-Wheels
Advantages • Powerful 50cc engine • Rugged steel chassis • Integrated Suspension • Longer Run Time • Rugged All-Terrain Tires • Increase Payload Capabilities	**Advantages** • Automation Complete • Tested and Works • Tighter Turning Radius • Reverse • Less Expensive Platform • Easier to Transport
Disadvantages • No Reverse • Larger Turning Radius • Cannot be tested indoors • Low-End Torque	**Disadvantages** • Marginal drive power • Plastic construction • Plastic Wheels / Tires • Battery-Limited Run Time • No Suspension

Through this comparison, the team selected the Suzuki Mini-Quad as the platform of choice. This choice was made based on a number of advantages to using this design including: increased run time, integrated suspension, rugged design, and payload capacity.

Power Systems

A key system discussed by the design team early in the design process was the power system. The team originally discussed a number of power storage and distribution systems ranging from the complex including alternators and custom charging circuitry to the most simplistic use of a number of batteries. These discussions were narrowed down to two primary choices.

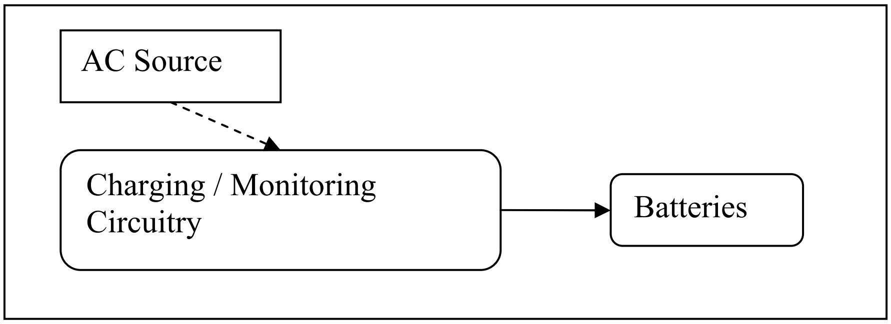

Figure 1 - Power Systems Option One

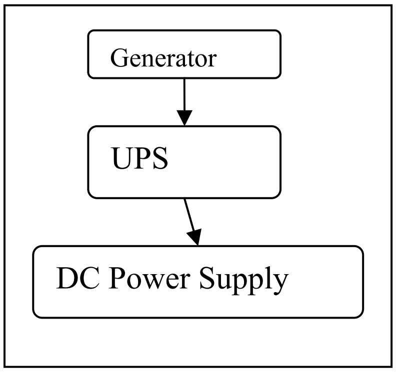

Figure 2 - Power Systems Option Two

Figure 1 shows the first system considered. It consists of a series of 12-volt batteries used to power the vehicle. Custom charging circuitry was to be designed and integrated into the vehicle to allow the system to switch from running off the battery supply to running off a provided AC power source. This system would have considerable battery life to run long periods (i.e. 8 hours) between charges. The second system considered is shown in Figure 2. This system uses a small AC generator as the primary power source. The generator is coupled to an uninterruptible power supply, which powers a DC power supply. The design team identified a number of advantages and disadvantages to each of these designs as outlined in Table 2.

Table 2 - Power Options Comparison

Power Systems Option One	**Power Systems Option Two**
Advantages: • Custom Solution fit to needs • Less space needed	**Advantages:** • Off-the-shelf parts • Fuel Supply limits run life • Equipment readily available • Tested, Known to work
Disadvantages: • Time consuming system design • Reliability of custom circuitry • Large number of DC batteries • Limited run time	**Disadvantages:** • Requires generator carried • Cannot be tested indoors • Large system weight

Based on these comparisons, the TailGator team identified option two as the best selection for meeting the vehicle's performance goals. This decision was based primarily on two factors. First, the team had prior experience with this system and knew it to work reliably and second, the other solution presented a complex electrical design problem which the team felt was unnecessary given the time and scope of this project.

Detailed Vehicle Design

Vehicle Specifications

The Suzuki LT-A50, a gas powered four-wheeler was chosen as the base platform for this year's entry. Vehicle pictures can be seen below in Figure 3. This platform was chosen because of its ruggedness as an all terrain vehicle. It is constructed of a tubular steel frame, comes stock with all terrain tires and suspension and built in safety kill switches. Other specifications can be seen in Table 3. The only limitation of the off-the-shelf vehicle is that its transmission does not allow for reverse. After much debate it was decided that the team's current capabilities in both obstacle avoidance and path planning would allow the vehicle to make correct decisions far enough in advance such that a reverse should not be needed.

Figure 3 - Suzuki LT-A50 Mini-Quad

Table 3 - Suzuki LT-A50 Specifications

Engine	49 cc, 2-stroke, air cooled, single cylinder
Transmission	1-speed - automatic
Overall Length	1260 mm (49.6 in.)
Overall Width	760 mm (29.9 in.)
Overall Height	745 mm (29.3 in.)
Ground Clearance	120 mm (4.7 in.)
Wheelbase	825 mm (32.5 in.)
Front Suspension	Single A-arm,, oil damped, coil spring
Rear Suspension	Swingarm, oil damped, coil spring
Fuel Tank Capacity	2.6 liter (0.7 gal.)

Vehicle Modifications

There were three modifications that needed to be done to the stock chassis in order to improve performance. The first modification was to remove an exhaust restrictor from the exhaust line as seen in Figure 4. After the removal of the restrictor the LT-A50 showed a significant increase in performance. The performance increase included a smoother idle at low speeds, faster throttle response, and an increase in torque and speed. The second modification was necessary in order to increase torque and decrease top speed. This modification was accomplished by changing the output gear ratio from its stock ratio of 37:12 to a ratio of 60:12. Details of this modification are covered in a later section. Lastly, the steering linkage of the stock vehicle was modified to allow for a tighter turning radius for the vehicle.

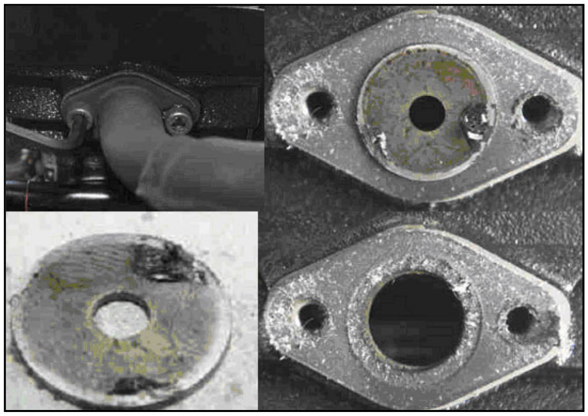

Figure 4 - Removal of Exhaust Restrictor

Automation

The design team first set out to automate the necessary vehicle components including steering, throttle and brake. The throttle and brake required a system to pull the control cable while the steering needed an actuator to revolve the steering column. With these requirements in mind, the design group went through a number of possible designs over a period of a month. Final design concepts were chosen and detailed design work began on the automation hardware.

Throttle and Brake Actuation

Since both the throttle and brakes were controlled via a pull cable, the team decided to implement a large-scale servo to pull the cables to the desired position. Testing revealed that the throttle cable needed a minimum of 10 pounds of force to engage while the brake needed a much higher 30 pounds. A large-scale servo capable of providing the required torque was found and incorporated into the design. The associated hardware was finalized and the throttle and brake systems built onto the vehicle. Initial testing revealed flaws in the original design. These flaws were not serious and minor design revisions were made to the system to overcome them.

Steering Actuation

Steering actuation was accomplished by mounting a Smart-motor 3000 and a 20:1 planetary gear-head in line with the steering column through the use of a coupling. The Smart-motor is a fully integrated motor that houses all of its drive components within its housing. The Smart-motor can be programmed and only needs direction signals and power. In order to protect the Smart motor from being back-driven a slip coupling was designed and integrated into the steering column coupling fixture as shown in Figure 5. The slip coupling was designed by cutting a thin slot in the steering shaft, which is hollow and putting a slightly smaller coupling over the shaft in

Figure 5 - Steering actuation with slip coupling

order to clamp down on the steering shaft that in turn will clamp down on the motor's shaft creating a friction slip fit. This slip coupling was then tightened to 40 ft-lb of torque and will fail by slipping before the motor is back driven.

Electrical Systems

Power Systems

The TailGator vehicle employs the use of a very robust and flexible power storage and distribution system. The team's goal of having the maximum possible runtime was accomplished through the use of a Honda EU1000i lightweight generator. This provides the vehicle's primary power source. The AC generator is used to charge an uninterruptible power supply on the vehicle that serves as a temporary power backup and also as a filter for the output power.

The AC power is converted to both 12-volts DC and 24-volts DC using AC-to-DC power supplies. The 12-volt power is used to run all vehicle electronics and computing resources. The 24-volt power is used solely to drive the steering motor. While the laser range finder also requires a 24-volt supply, the team decided not to power it from the 24-volt supply provided by the AC power supply. Instead each subsystem on the vehicle is required to take as input 12-volts and use that supply to create any other voltages needed by the system to power its various components. Thus the detection and mapping unit which is included in the mobility control unit is required to convert 12-volts to 24-volts for the laser. This ensures interoperability across a number of vehicle systems.

Power distribution is accomplished inside a custom-built enclosure at the rear of the vehicle. This enclosure incorporates the use of female Amphenol connectors on its front panel to ensure that individuals cannot hurt themselves or equipment by shorting across the terminals. The enclosure is shown in Figure 6.

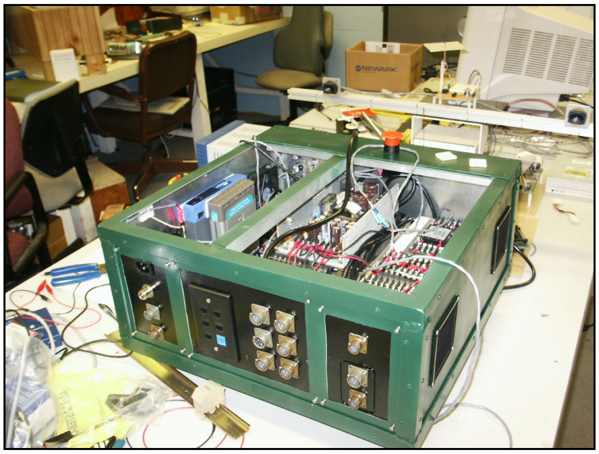

Figure 6 - Power Systems Enclosure

Safety Kill Mechanisms

As required by the IGVC rules and necessary in any design of this nature, the TailGator vehicle includes a number of methods to safely disable the vehicle. These safety systems consist of two remote kill channels and an emergency stop button on the vehicle. The Suzuki LT-A50 came equipped with a safety disable feature built in. This consisted of a signal, which when disconnected, arrests the spark plug and efficiently disables the vehicle's motor. This cannot be restarted autonomously. The design team refers to this as the Hard Kill channel. The hard kill can be triggered either by one of the channels on the remote kill system or the emergency button located on the vehicle. The second remote channel corresponds to a Soft Kill channel on the vehicle. This signals an interrupt to the primitive driver component, which will cause the driver to stop the vehicle in a more controlled manner than killing the motor. This also causes the primitive driver component to declare an emergency state on the vehicle, transmit that state to other system components and stop responding to input wrench commands until the interrupt is cleared. It is the team's desire to primarily use the soft kill on the vehicle, but the hard kill is a solid and reliable backup in case of a software issue.

Computing Systems and Software

Primitive Driver Component

The TailGator's primitive driver is built on a RabbitCore 3200 embedded controller. Three things were necessary for the primitive driver to fulfill its functions on the vehicle. It must be capable of communicating with the rest of the system over an Ethernet connection using JAUS messages, it must be able to generate the pulse-width modulated signal for the brake and throttle actuators, and it must be able to communicate with the steering motor over a serial connection. The RabbitCore 3200 unit fulfilled these needs while providing a small integrated computing resource. The Rabbit processor runs at 44.2 MHz, providing the necessary speed to respond quickly to messages routed to it through the network connection.

The primitive driver takes an incoming wrench message that contains data for both resistive and propulsive linear and rotational efforts along all three vehicle axes. The TailGator platform can only respond to three of these efforts, a linear effort in the forward direction, a linear effort opposite that, and a rotational effort about the center of the vehicle. The rotational effort is mapped to the steering actuation. The resistive linear effort corresponds to brake actuation and the propulsive linear effort is throttle control. The throttle and brake actuators were calibrated to provide the greatest resolution available and scaled linearly within that range.

Position System Component

The position system onboard the TailGator, is a combination of GPS, shaft encoder, and magnetic compass information. The system uses a Novatel GPS and a PNI digital compass. The position system is used to determine the vehicle's global position, and forward velocity. The system combines the data from all three of its sensors in a weighted averaging filter to improve the stability and minimize the drift of the GPS.

The shaft encoder is mounted to the rear axle of the TailGator and outputs quadrature signals that indicate the axle rotation angle and direction of rotation. These signals are decoded by a microcontroller, which stores the relative encoder position in integer form. The microcontroller is also used to read and parse the digital compass serially transmitted data. The information for both the encoder and compass is collected at a rate of 10 Hz and then sent to a single board computer running Linux via a serial port. The GPS data is also received and parsed by the single board computer. Once the Linux computer has received the data from the shaft encoder, GPS, and digital compass, it filters the data together using a weighted average filter. Figure 7 shows simulated results of this filtering method.

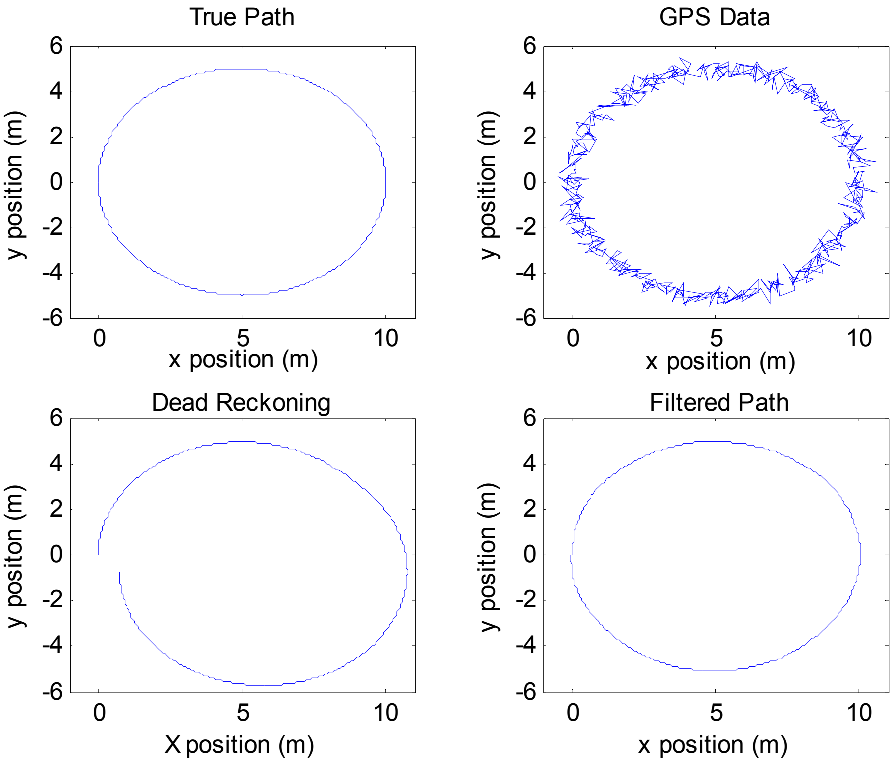

Figure 7 - Weighted Filter Results

The image in the upper left of Figure 7 represents the simulated true path of the vehicle. The image in the upper right represented simulated GPS data. The image in the lower left is the simulated output from the encoder modeled with wheel slip error. The image in the lower right represents the weighted average output of the two. Testing on the vehicle platform has shown similar repeatable and reliable results. A discrete time derivative of the encoder data is also calculated in order to determine the vehicle speed. The position and velocity data is transmitted to the sub-system commander via the Global Pose Sensor and Velocity State Sensor messages outlined in the JAUS document.

System Integration

The Sub-System Commander Component (SSC) provides the connectivity of all of the vehicle's sensors and actuators to the higher-level software. The SSC links all of the computing units to achieve the desired overall system control. By connecting all of the lower level computing units and software to this system, the SSC can coordinate vehicle automation by receiving and issuing JAUS messages. The JAUS message framework provides a robust and concrete methodology for system integration in this regard. Figure 8 shows the overall system organization with all of the data connections for the various parts of the autonomous system.

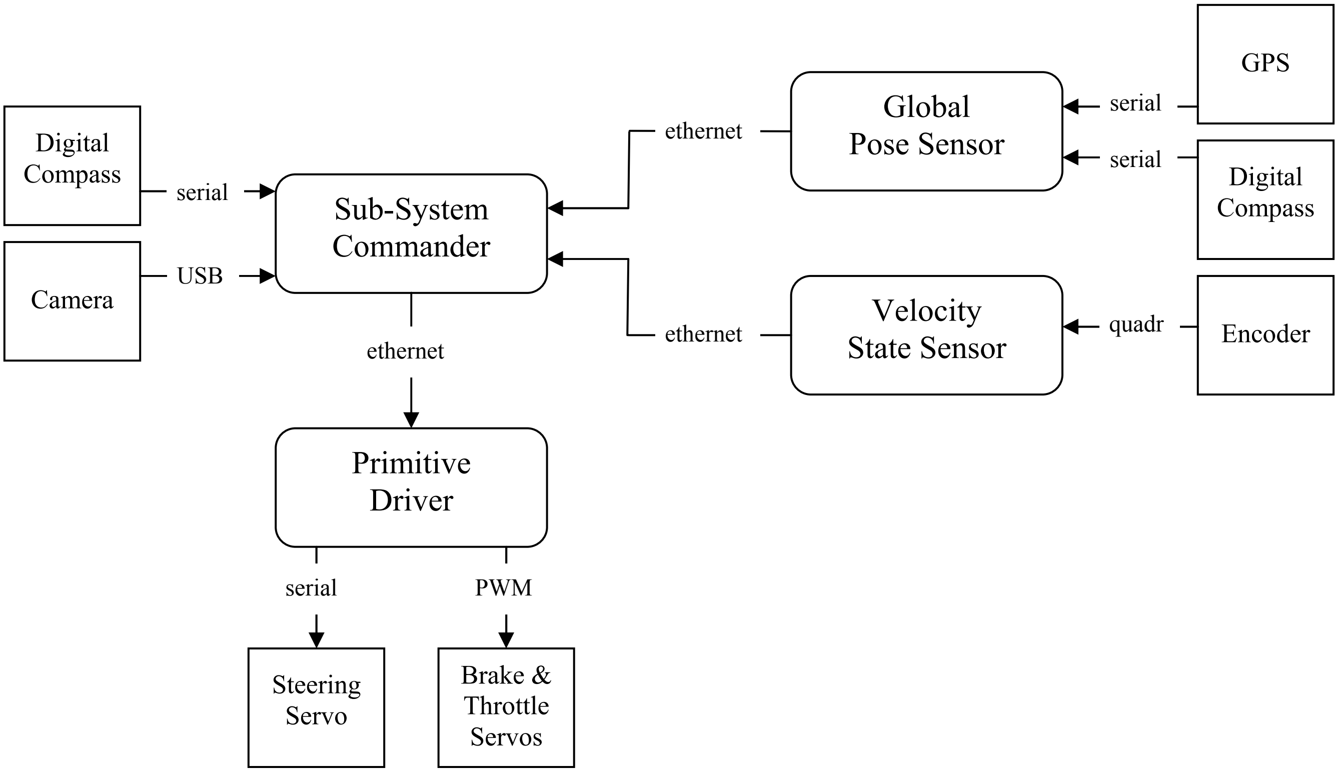

Figure 8 - System Components and Signals

Sub-System Commander Component (SSC)

The purpose of the SSC is to gather information about the vehicle and its surroundings, perform high-level decision-making and planning operations, and issue motion commands to the primitive driver component. The Sick laser range finder is used to detect spatial obstacles while the camera detects visual obstacles. Based on this information the SSC is able to determine a safe path to traverse. Once a desired path has been formulated the SSC controls the actuators to execute the desired path. The internal controllers within the SSC use the position system feedback to perform closed loop control.

Image Processing

Several advanced image processing and classification algorithms were developed to extract the white lines and potholes. A Philips USB web camera is used to gather visual information about the environment.

The maximum likelihood estimation (ML) technique is a statistical modeling technique that can be applied to multi-dimensional data sets. By using the model created by this technique the probability of each pixel is calculated which is used for classification.

Figure 9 describes the method by which the probability of each pixel is calculated and presents sample image data and classified data. The classification performance is affected by tuning the probability threshold.

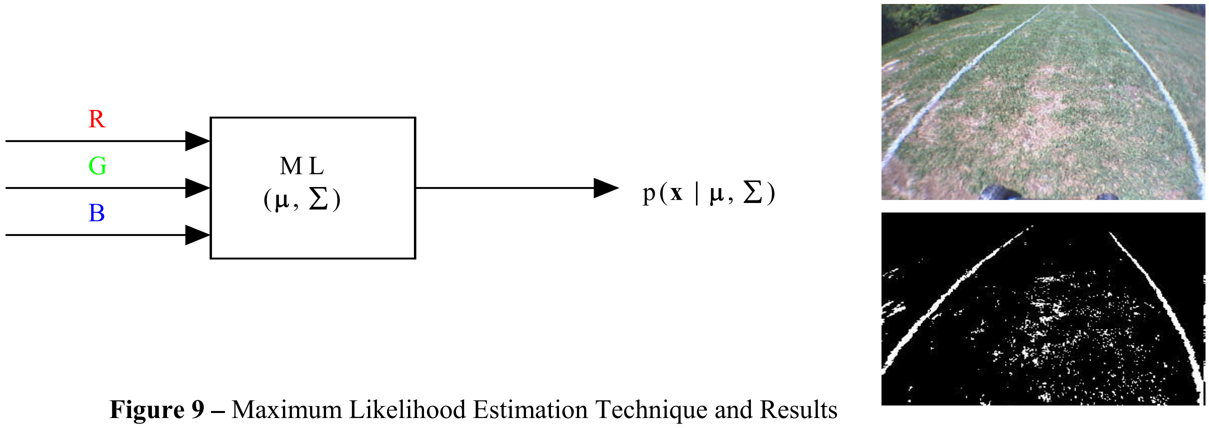

Figure 9 – Maximum Likelihood Estimation Technique and Results

The next method that was developed utilized an artificial neural network (ANN) to classify the image data. A classifier was developed using a single hidden layer, multilayer perceptron network. The neural network was trained using sample image data. The algorithm operates similar to the maximum likelihood technique except that this technique takes the pixel data and passes it through a trained artificial neural network with a non-linear response. Figure 10 illustrates the concept of the neural network algorithm and corresponding results.

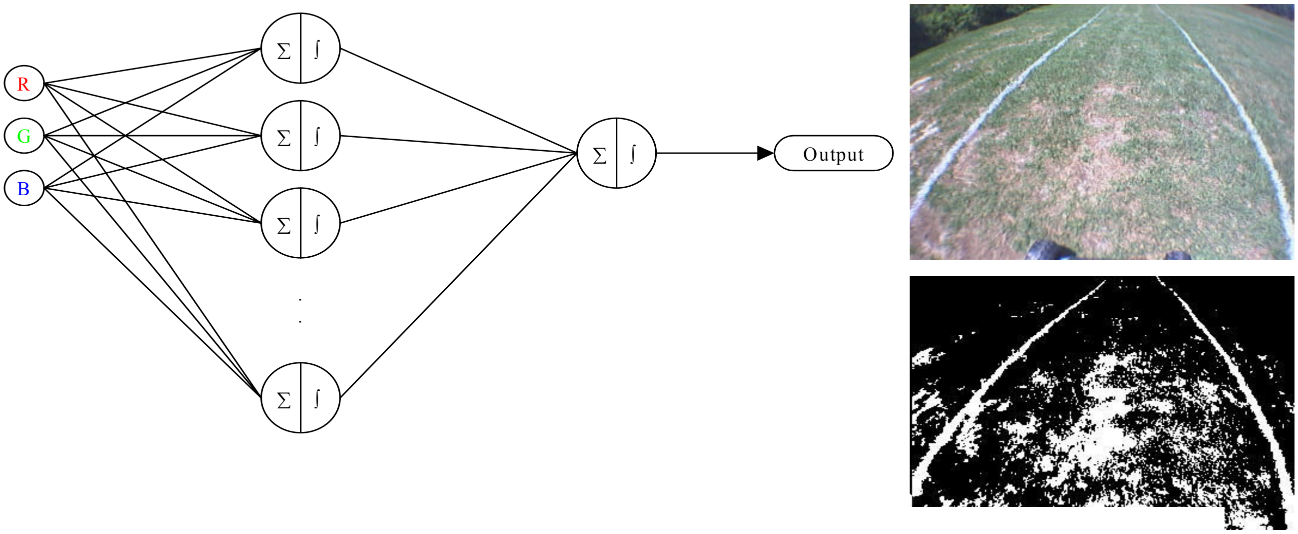

Figure 10 – Artificial Neural Network Algorithm and Results

Another algorithm was developed so that classification could be performed without the need for a color model. The idea was to develop a classifier based solely on spatial properties of regions of similar color and proximity. The spatial statistics classifier (SSC) utilizes preprocessing techniques such as principal component analysis and vector quantization to reduce the data set and to break the image into regions of similar properties.

Illustration of the spatial statistics classifier and sample image data and corresponding results are shown in Figure 11.

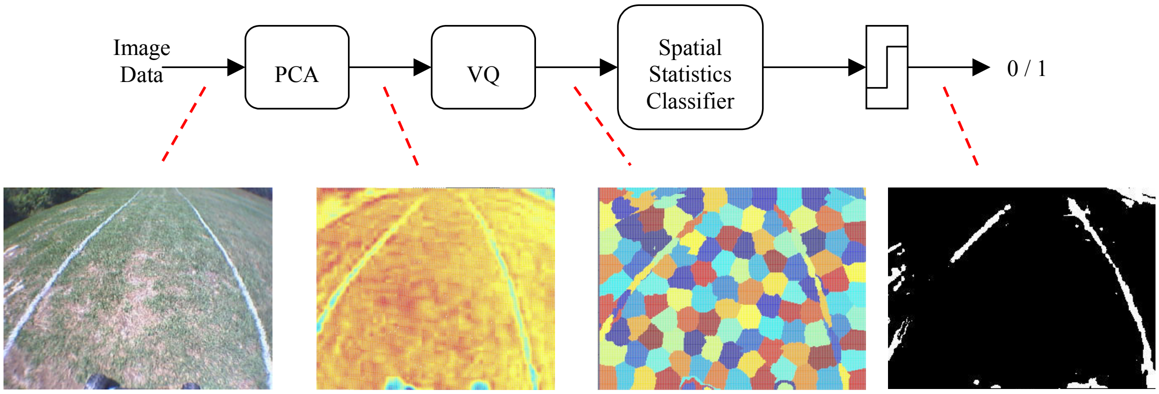

Figure 11 - Spatial Statistics Classifier

These three methods were combined to form two "mixture of experts" algorithms. The first mixture of experts algorithm is composed of the ML and SSC algorithms. The second mixture of experts algorithm is composed of the ANN and SSC algorithms. Figure 12 compares the image data and the two mixture of experts techniques. Both techniques provide adequate results and process in approximately the same time at a rate of 1 Hz.

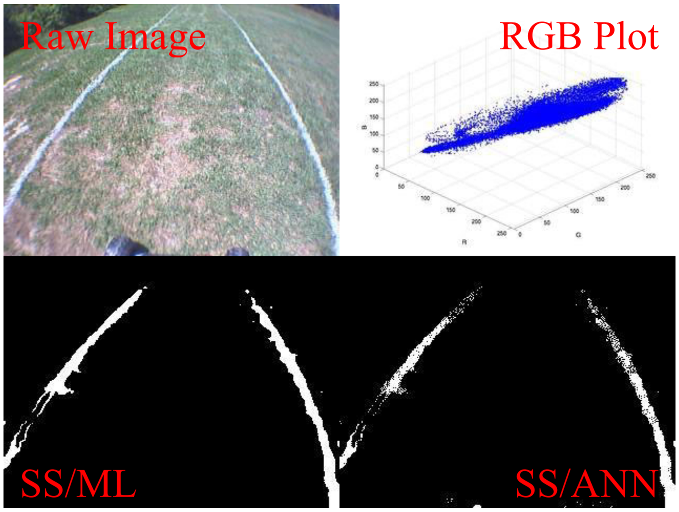

Figure 12 – Comparison of Spatial Statistics coupled with Maximum Likelihood and Spatial Statistics coupled with Artificial Nueral Network outputs

Obstacle Detection, Avoidance and Path Planning

The spatial obstacles are detected using a Sick Laser Measurement System (see Figure 13). The visual local grid map and spatial local grid map are combined to form an overall local grid map. The local grid map and the vehicle parameters are utilized by the path planner to determine an unobstructed desired heading. During the Autonomous Challenge, the local grid map data from the image processing

Figure 13 - SICK LADAR

software is fused with the spatial data. This combined data is run through the path planner to find the optimal desired heading. In the Navigation Challenge the spatial data is combined with the waypoint driver output to find the optimal path. The diagram in Figure 14 illustrates the collision avoidance algorithm.

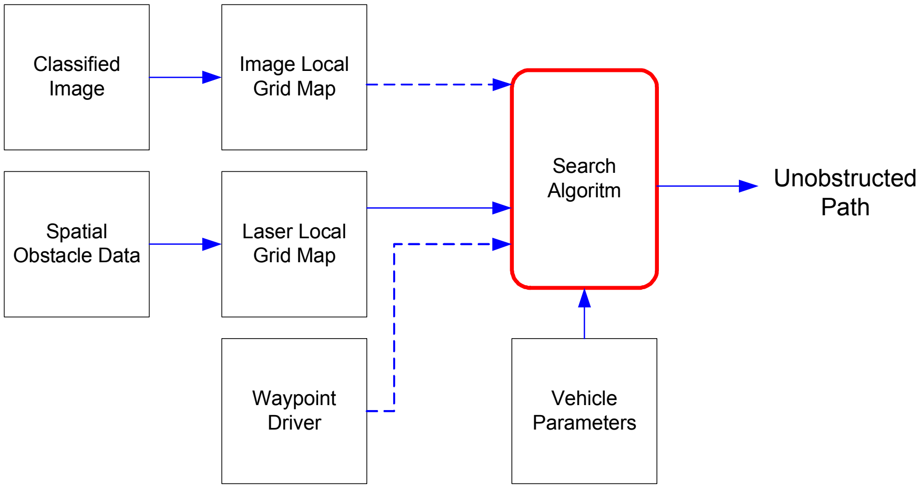

Figure 14 - Collision Avoidance Algorithm

Prototype Development & Testing

During testing of the prototype vehicle and its various subcomponents, the team discovered areas of concern in the vehicle's performance. The areas included vehicle torque performance and the performance of the position system.

Torque Requirements

Upon initial testing of the original vehicle, it was found that the torque required to climb a ramp was lacking. With a payload of approximately 120 pounds the vehicle would begin to climb the ramp and stall before reaching the peak of the ramp.

Changing the rear sprocket on the vehicle solved this problem. The original sprocket had 37 teeth. The team was able to obtain a sprocket that was larger, i.e. had more teeth, and specifically designed for this model vehicle. The new sprocket has 60 teeth. This modification provided a 66% torque increase. The new sprocket is shown in Figure 15.

Figure 15 - New Rear Sprocket

Position System Component Microcontroller

The original designs for the position system component included the use of a RabbitCore 3200 microprocessor to parse and filter the data and transmit the appropriate JAUS message. After completion of the original system, the design team struggled with achieving sufficient GPS accuracy from the system. Further inspection of the situation showed that the lack of floating point hardware on the RabbitCore module caused a loss of precision in the data beyond the fourth decimal place. This fourth decimal place corresponds to about 600 inches. The design team had to find another solution that would ensure higher accuracy. The encoder unit requires quadrature decoding. The RabbitCore module included quadrature decoding in its functionality and no other method to decode the signal was readily available. A hybrid solution was chosen and implemented. As outlined in the position system section, the microprocessor is used to decode the quadrature signal and parse the data from the digital compass. This data is then sent via RS232 to a single board computer running Linux. The single board computer also takes in the serial data from the GPS, combines it with the data from the microprocessor and transmits the Global Pose Sensor and Velocity State Sensor JAUS messages. The flexibility of the JAUS architecture made this transition less time consuming and relatively painless for the design team.

Vehicle Performance Analysis

The TailGator vehicle meets or exceeds all performance criteria placed on it by both the design team's goals and the IGVC competition. The gear train on the system has been modified to provide more low-end torque, therefore reducing the vehicle's top speed to just below five miles per hour and increasing ramp climbing ability. In testing, the vehicle has traversed inclines in excess of 30°. The use of a gasoline-powered vehicle coupled with an AC generator provides TailGator with an extended runtime, limited only by the supply of fuel. The laser range finder onboard the vehicle is capable of detecting obstacles at a distance of 80 meters, giving the path planning algorithm significant time to devise a reliable path around obstacles while avoiding traps and dead ends. The Novatel GPS uses WAAS correction signals to achieve sub-meter accuracy while the PNI compass module provides heading data accurate +/- one degree. Testing has shown waypoint accuracy of approximately one meter. The weighted average filter essentially eliminates lateral deviation of the vehicle's position.

Team Members

Table 4 - Team Members and Grade Level

Name	Level	Dept
Carl Evans	Graduate Student – MS	MAE
Tom Galluzzo	Graduate Student – PhD	MAE
Danny Kent	Graduate Student – MS	MAE
Donald MacArthur	Graduate Student – PhD	MAE
Roberto Montane	Graduate Student – PhD	MAE
Duk Sun Yun	Post Doctorate	MAE
Erica Zawodny	Graduate Student – PhD	MAE

Estimated man-hours of work to complete project:

Mechanical Systems:	500	Electrical Hardware:	400
Computers and Software:	900	Systems Integration:	250
Testing & Evaluation:	1000		

Total: 3050

Cost Analysis

Table 5- Cost Breakdown

Part	Manufacturer / Model	QTY	Total Cost
Base Vehicle	Suzuki LT-A50 Mini-Quad	1	$2,000
Steering Motor	Smart Motor 3000	1	$3,000
Servos	Large Scale Ball Bearing Servos	2	$100
Generator	Honda EU1000i	1	$1,000
UPS	APC	1	$120
Power Supplies	12 Volt & 24 Volt DC	1	$1,000
GPS	Novatel MiLLennium GPSCard	1	$3,500
Laser Range Finger	SICK	1	$6,000
Digital Compass	PNI TCM2-50	1	$800
Shaft Encoder	Dynapar Shaft Encoders	1	$300
Remote Kill	Seco-Larm SK-910R2	1	$90
Single Board Computer	MFG / MODEL	1	$1000
Microprocessor	RabbitCore 3200	2	$250
Laptop	DELL Inspiron	1	$1600
Misc Hardware	Miscellaneous	1	$1,000

Total: $21,760

Acknowledgements

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