A Technical Report on

TAILGATOR

Submitted to:
William G. Agnew

12th Annual Intelligent Ground Vehicle Competition
June 2004

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 was built to compete in the Intelligent Ground Vehicle Competition. TailGator must be capable of competing in the two challenges presented by the competition, the Autonomous Challenge and the Navigation Challenge. The Autonomous Challenge requires the autonomous navigation of TailGator through an obstacle course of visual and spatial obstacles whilst carrying a 20 pound payload. The Navigation Challenge requires the autonomous navigation of TailGator to a series of waypoints whilst avoiding spatial obstacles and carrying a 20 pound payload.

In addition, the vehicle was designed and implemented to be compliant with the Joint Architecture for Unmanned Systems (JAUS) reference architecture to take advantage of the many benefits of a structured architecture and 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 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 gets passed to and from 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.

DESIGN

MOBILITY

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 chose to use a commercially available vehicle as a base platform that was automated. A Suzuki Mini-Quad all-terrain vehicle was selected based on its extended run time, integrated suspension, rugged design, and payload capacity.

Vehicle Specifications

The Suzuki LT-A50, a gas powered, four wheel, all terrain vehicle was chosen as the base platform. Vehicle pictures are shown in Figure 1. 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 1. The only limitation of the off-the-shelf vehicle is that its transmission does not allow for reverse. It was decided that the vehicle's current capabilities in both obstacle avoidance and path planning would allow for correct decisions far enough in advance such that a reverse should not be required.

Figure 1 - Suzuki LT-A50 Mini-Quad

Table 1 - 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.)

PERCEPTION

Image Processing

Image processing and classification algorithms were developed to extract the white lines and potholes. An industrial, color CCD camera with an auto-iris lens is used to gather visual information about the environment (see Figure 2).

Figure 2: CCD Camera

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 3 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.

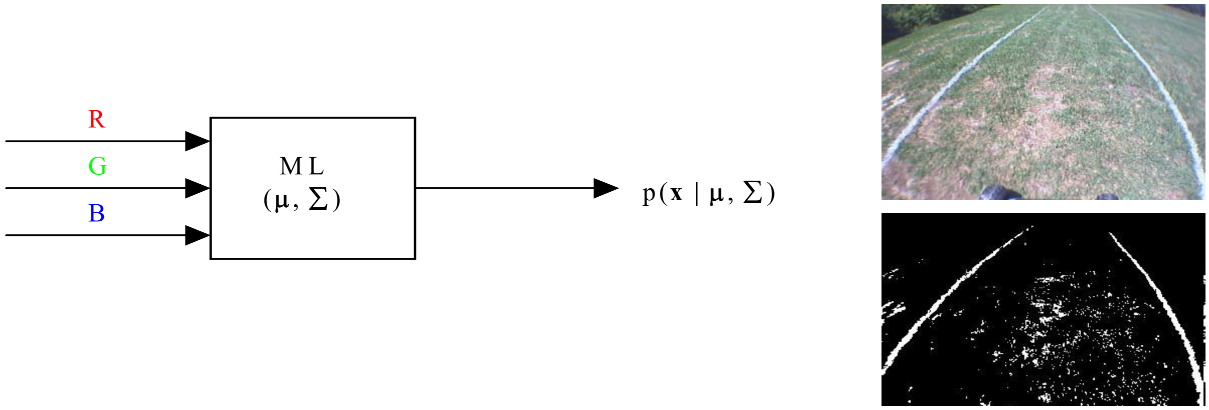


Figure 3 – Maximum Likelihood Estimation Technique and Results

POWER

Power Systems

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.

The desired power system had to have a long run time (greater than two hours), fast charge/no charge time (less than one hour), a battery backup system, and provide 120 VAC, 5 VDC, 12 VDC, and 24 VDC. A diagram of the power system is shown in Figure 4.

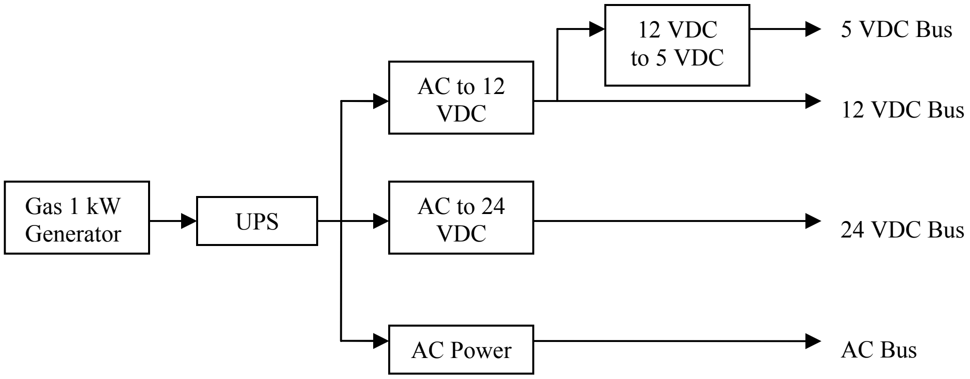


Figure 4: Power System Diagram

IMPLEMENTATION

MOBILITY

Vehicle Modifications

There were three modifications that were made to the base chassis in order to improve performance. The first modification was to remove an exhaust restrictor from the exhaust line as seen in Figure 5. 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. Lastly, the steering linkage of the stock vehicle was modified to allow for a tighter turning radius for the vehicle.

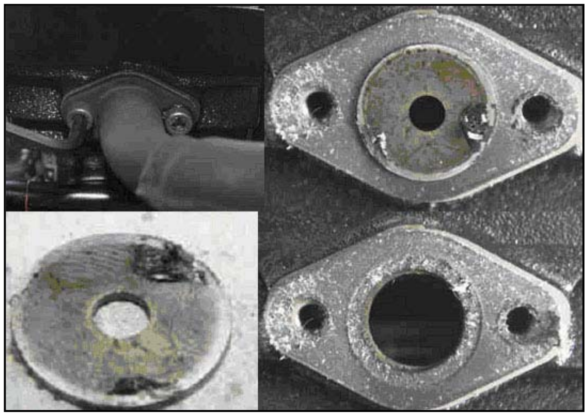


Figure 5 - Removal of Exhaust Restrictor

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 was not capable of climbing a test ramp of a similar incline as stated in the IGVC rules.

By changing the rear sprocket of the vehicle's transmission from a 37 tooth sprocket to a 60 tooth sprocket the torque was increased by 66%. This modification enabled the vehicle to climb the test ramp with a payload of greater than 180 pounds. The new sprocket is shown in Figure 6.

Figure 6 - New Rear Sprocket

Automation

The design team first set out to automate the steering, throttle and braking systems. The throttle and brake systems were cable driven while the steering system required an actuator to revolve the steering column.

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 at least 30 pounds. A large-scale servo capable of providing the required torque was found and incorporated into the design.

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 using a Lovejoy coupler. The Smart-motor is a fully integrated motor that is composed of an amplifier, encoder, servo motor, controller, and gear-head in one complete package. The Smart-motor is programmable and uses a simple serial interface. 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 7. The slip coupling was designed by cutting a thin slot in the hollow steering shaft, and placing a compression device around the steering shaft and the motor interface shaft which in turn clamped down on the motor's shaft creating a friction slip fit. This slip coupling was then tightened such that the joint would slip at greater than 40 ft-lb of torque. Since the motor had a stall torque of 40 ft-lb this would prevent the motor from being back-driven.

Figure 7: Steering Actuator

PERCEPTION

Position System Component

The position system onboard the TailGator, utilizes a combination of GPS, shaft encoder, and magnetic compass information. The system uses a Garmin GPS 16, PNI digital compass, and a Dynapar shaft encoder. 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 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 via a serial port. The GPS data is also received and parsed by the single board computer. Once the single board computer has received the data from the shaft encoder, GPS, and digital compass, it filters the data together using a weighted average filter. Figure 8 shows simulated results of this filtering method.

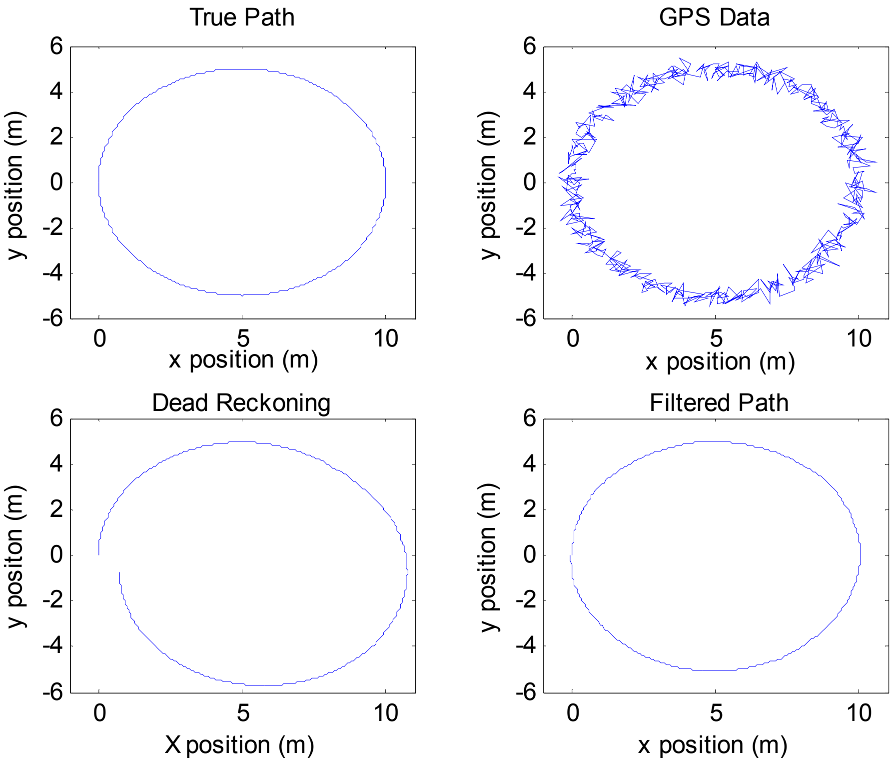
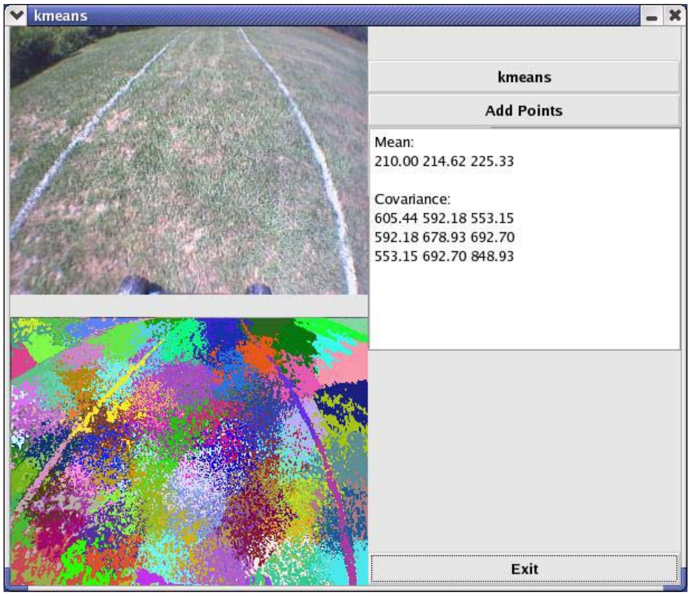


Figure 8 - Weighted Filter Results

The image in the upper left of Figure 8 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.

Image Processing

A segmentation tool facilitated development of a color model for the white lines. This program was a pre-processing tool that was used to extract white lines from an image. The extracted pixels are then used to build a statistical model of the white lines. This is an offline program that is useful when it is necessary to build a statistical model based on color. A graphical user interface was developed and is shown in Figure 9.



```
Mean:
210.00 214.62 225.33

Covariance:
605.44 592.18 553.15
592.18 678.93 692.70
553.15 692.70 848.93
```

Figure 9: Segmentation Program

For debugging and testing purposes a graphical user interface was developed to display camera and laser data. In addition, this program displays current vehicle state and parameters such as position, velocity, and current heading. This gives the operator access to different levels of data during testing. A sample of the interface is shown in Figure 10.

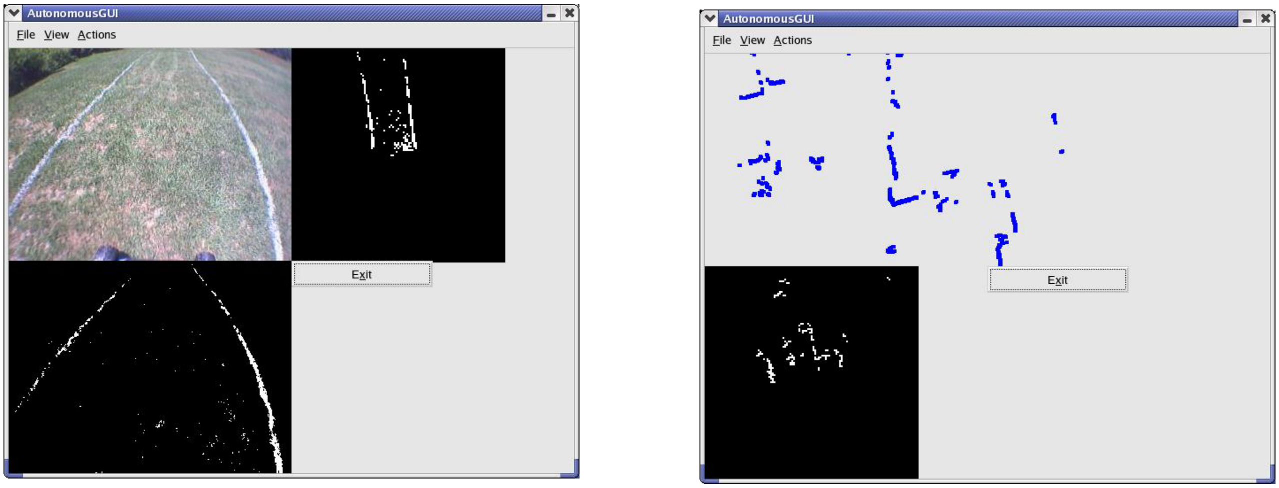


Figure 10: Images from the Camera and Laser Screens

POWER

Long run time was achieved by using an efficient four-stroke gasoline generator to act as the main power source. Under typical loading conditions, the system achieved run times of four to six hours between fuelings. By coupling the generator with an uninterruptible power supply (UPS) the generator could be refueled without powering down computer systems, thus providing zero downtime when replenishing the power supply. This also provided a factor of safety for safe shutdown of all systems in the case of fuel exhaustion. Several AC to DC converters along with DC to DC converters provided the appropriate voltages to all electronic hardware.

The TailGator vehicle employs the use of a robust power distribution system. The goal of having maximum possible runtime was accomplished using a Honda EU1000i 1 kW generator. This provides the vehicle's primary power source. The AC generator is used to charge an uninterruptible power supply (UPS) 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. A detailed diagram of the power system is shown in Figure 11.

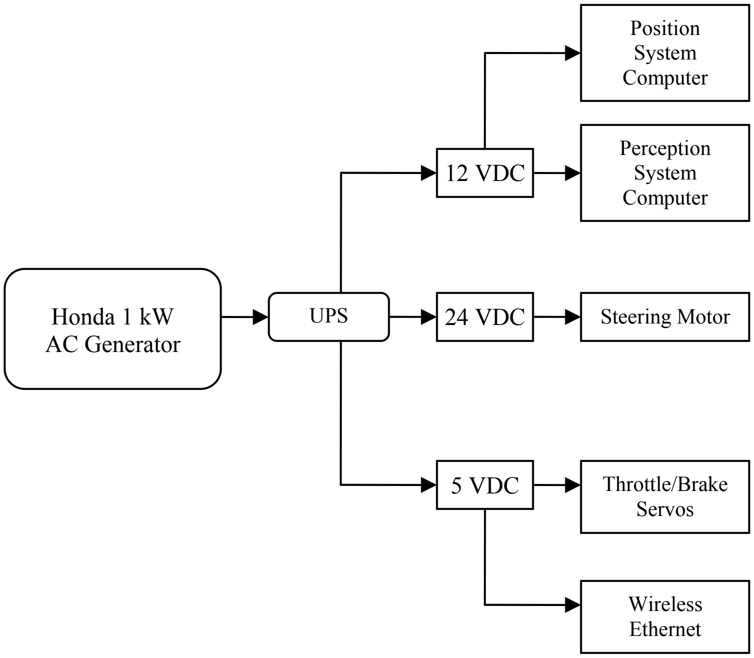


Figure 11: Detailed Power System Diagram

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 avoid injury and damage to equipment caused by shorting across the terminals.

CONTROL AND INTELLIGENCE

Primitive Driver Component

The TailGator's primitive driver is built on a RabbitCore 3200 embedded controller. This controller must be capable of communicating with the system network over an Ethernet connection using JAUS messages, generate the pulse-width modulated signal for the brake and throttle actuators, and perform serial communication with the steering motor. 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, propulsive, 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 resistive linear effort, 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.

Sub-System Commander Component

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.

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 12 shows the overall system organization with all of the data connections for the various parts of the autonomous system.

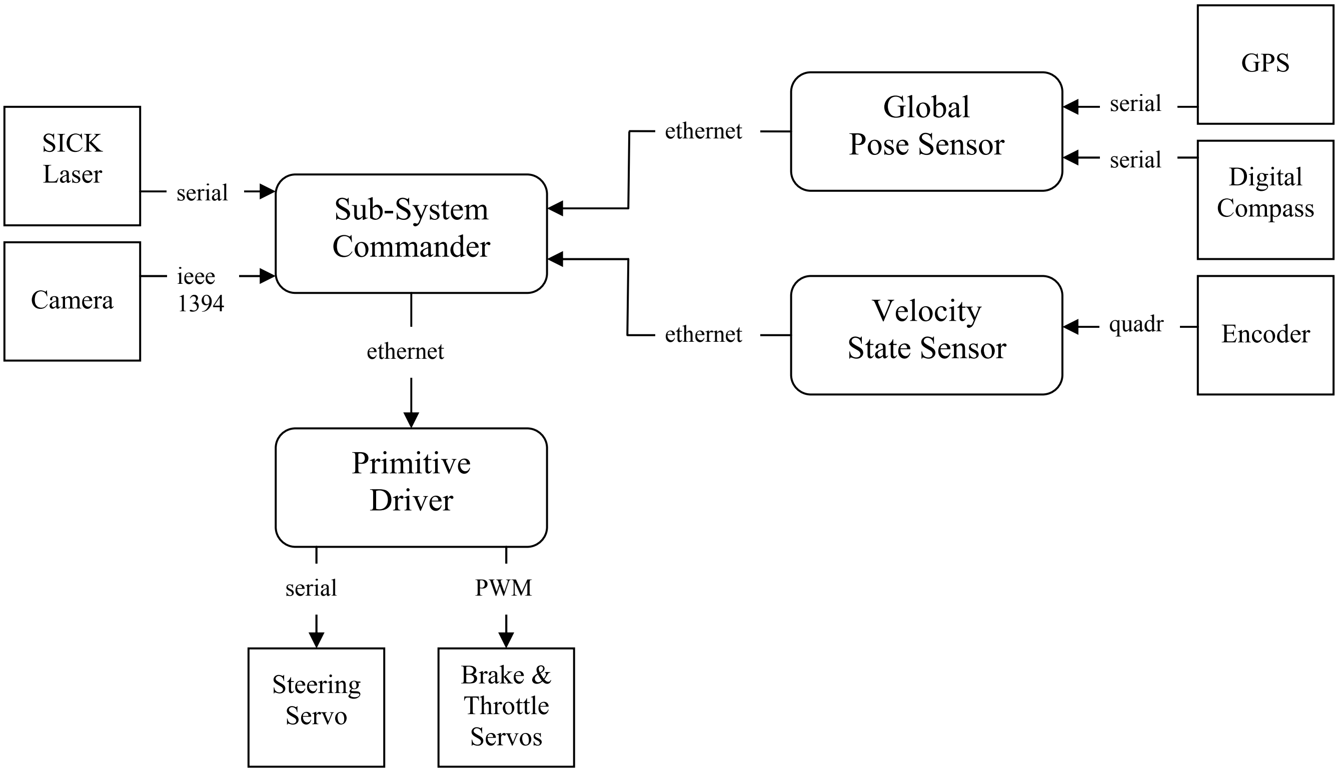


Figure 12 - System Components and Signals

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 software is fused with the spatial data. This combined data is processed by 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 13: SICK Laser

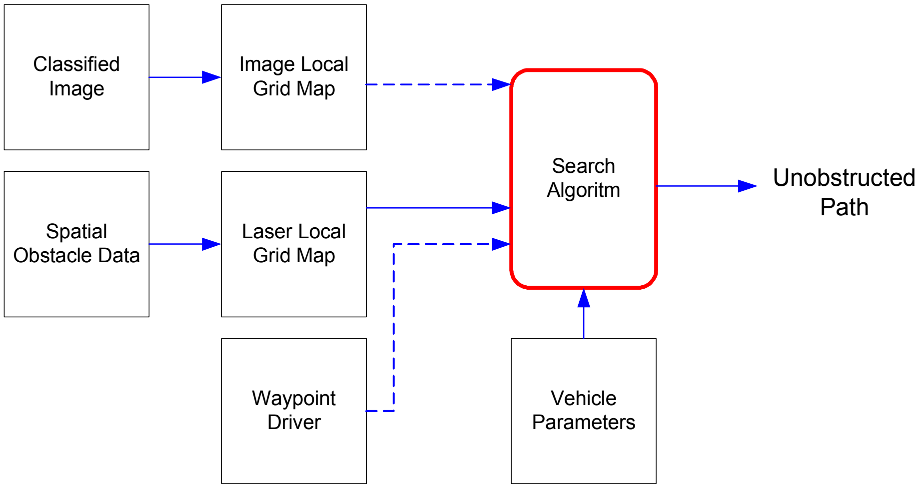


Figure 14: Collision and Obstacle Avoidance Algorithm

Safety Kill Mechanisms

As required by the IGVC rules, 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. This is referred to 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 allow the operator 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.

TESTING

During testing of the prototype vehicle and its various subcomponents, the team discovered areas of concern in the vehicle's performance. The performance of the position system was evaluated through rigorous testing.

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. The original system design did not provide sufficient GPS accuracy. 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 corresponded to about 600 inches. The system design required modification to allow for higher precision GPS measurements. The position system also incorporated an encoder unit which required quadrature decoding. The RabbitCore module included quadrature decoding in its functionality. A hybrid solution was chosen and implemented in which the microprocessor was used to decode the quadrature signal and parse the data from the digital compass. This data is then sent serially to a single board computer. In addition the single board computer received the serial data from the GPS, combined it with the data from the microprocessor and transmitted the Global Pose Sensor and Velocity State Sensor JAUS messages. The flexibility of the JAUS architecture thus reduced the transition time from the original to the hybrid system design.

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 Garmin GPS used 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 2 - Team Members and Grade Level

Name	Level	Dept
Maryum Ahmed	Graduate Student – MS	MAE
Tom Galluzzo	Graduate Student – PhD	MAE
Donald MacArthur	Graduate Student – PhD	MAE
Sanjay Solanki	Graduate Student – PhD	MAE
Erica Zawodny	Graduate Student – PhD	MAE

Estimated man-hours of work to complete project:
Mechanical Systems: 500 Electrical Hardware: 400
Computers and Software: 1200 Systems Integration: 500
Testing & Evaluation: 1800

Total: 4400

Cost Analysis

Table 3- 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	Garmin GPS16	1	$200
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
Industrial CCD Camera	Appro	1	$235
Video Conversion Boards	Cannopus	1	$150
Compact Flash Drives	Sandisk (1GB)	2	$150
Single Board Computer	MFG / MODEL	2	$1000
Microprocessor	RabbitCore 3200	2	$250
Misc Hardware	Miscellaneous	1	$1,000

Total: $18,895

Acknowledgements

The design team would like to gratefully acknowledge the support provided by the Air Force Research Laboratory at Tyndall Air Force Base, Applied Research Associates, Inc., Wintec, Inc., Precision Navigation Inc., RK Racing Chain, and Rebel Gears.