EMBRY-RIDDLE
AERONAUTICAL UNIVERSITY

Presents

Reagle IV

Team members:

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Faculty Advisor Statement: I certify that the engineering design of the vehicle described in this report, Reagle IV, has been significant and is equivalent to that required in a senior design project.

1 INTRODUCTION

The 2010-2011 Embry Riddle Autonomous Ground Vehicle Team is proud to present Reagle IV, a vastly improved and upgraded version of a successful prior entry in the IGVC. Like the previous versions of Reagle and many other top competitors, Reagle IV is a three-wheel, differentially steered platform. To successfully navigate at the higher speeds allowed by the new IGVC rules, Reagle IV includes a tuned trailing arm suspension and other improvements to mitigate the effects of shock and vibration. Reagle's software has also been dramatically improved to allow faster update rates and to make it more adaptable to the new and less certain elements of the 2011 competition.

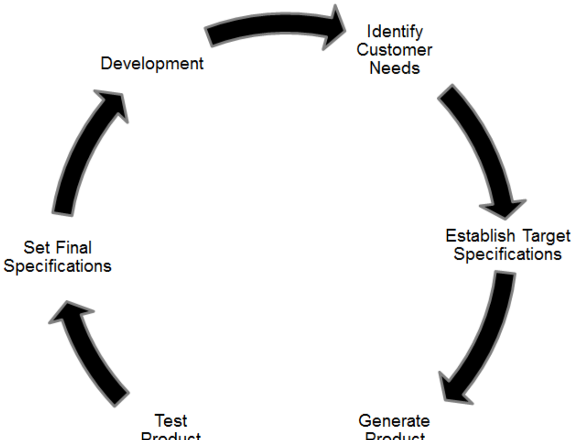


Figure 2.1:
Ulrich and Eppinger's Design Methodology

2 DESIGN PROCESS

The design team followed Ulrich and Eppinger's six step design methodology shown in figure 2.1 to further develop the Reagle IV platform.

2.1 Identify Customer Needs

Reagle's primary customers are the IGVC judges, the faculty advisors, and team members. Thus, Reagle IV strove to satisfy the new IGVC competition rules, as well as the faculty advisor's course guidelines.

2.2 Establish Target Specifications

In developing Reagle IV, the design team focused on improving an already solid vehicle. Some pressing issues the design team decided to address after last year's competition were: 1) modifying the vehicle to handle the updated maximum speed of 10 mph; 2) developing a more convenient and efficient method of troubleshooting problems when they arise; 3) stabilizing the electrical system so that sensitive components are not damaged by shock and vibration loads; and 4) upgrading and improving the software to meet the challenges of the new competition rules. The design team successfully addressed all four of these issues this year.

2.3 Concept Design and Testing

Once the desired improvements were determined and performance specifications were quantified, the team began to generate and test prototype concepts. Various approaches were considered to deal with the increased speeds and added complexity in the new competition. The most visible resulting improvement on Reagle IV is the trailing arm suspension system added to the traditional three-wheel delta chassis. Two other innovations, the voltage health monitoring system and ReagleLift Pro, make diagnosing problems and repairing Reagle IV easier. A small but significant improvement is the addition of a separate foam pad suspension system for just the electronics box that helps to isolate the electronics from vibration. Also, to ensure reliable electrical connections, a completely new set of wire harnesses was fabricated and installed on Reagle IV. Perhaps the most important but least visible changes to Reagle are software improvements. Legacy code was adapted and new code was written to account for the flags and GPS waypoints in the Autonomous Challenge and to improve the speed, reliability and adaptability of the code.

2.4 The Kano Method

The design team adopted a design philosophy known as the Kano method to help stimulate innovation. The Kano method divides features into three categories: basic features, performance features, and “delighters”. The vehicle already contained all basic features of an autonomous vehicle, so those were retained. Performance improvements include the new suspension system that increases top autonomous speeds and a more reliable electrical system and faster software. Delighters include the unexpected innovations described in section 3 that dramatically improve customer satisfaction.

2.5 Team Organization

Members of team Reagle IV are listed below with their respective areas of concentration. This consists of five team categories including mechanical design, software, electrical, documentation, and CAD.

Table 2.1: Team Organization Chart

		Areas of Concentration				
Team Member	**Academic Major**	**Mechanical**	**Software**	**Electrical**	**Documentation**	**CAD**
(TL) Christine Dailey	Mechanical Engineering	☑	☑	☑	☑	☐
Gregg Leonard	Mechanical Engineering	☑	☐	☑	☑	☑
Lin Lin	Mechanical Engineering	☑	☐	☐	☑	☐
David Harrison	Mechanical Engineering	☑	☐	☑	☑	☐
Mark Freeman	Mechanical Engineering	☑	☐	☐	☑	☐
William Meng	Mechanical Engineering	☑	☐	☐	☑	☐
Danny Reyes	Mechanical Engineering	☑	☑	☐	☐	☐
Jameson Pietrowski	Aerospace Engineering	☐	☑	☐	☐	☐
Matt Standifer	Mechanical Engineering	☑	☐	☑	☑	☐
Catherine Cruz Agusto	Software Engineering	☐	☑	☑	☑	☐
Eric Harmotz	Aeronautical Engineering	☐	☑	☐	☐	☐
Alaric Pain	Software Engineering	☐	☑	☐	☐	☐
Jake Bryan	Computer Engineering	☐	☑	☐	☐	☐
(TL) - Team Lead						

3 DESIGN INNOVATIONS

3.1 Voltage Health Monitoring System

The Voltage Health Monitoring System shown provides an innovative upgrade to the Reagle IV platform. The operator interface for this system is shown in Figure 3.1 This system helps diagnose electrical problems by displaying the voltage for all major voltage sources and sinks on panel-mounted digital displays, allowing for quick references and troubleshooting during vehicle operation. Real-time voltage readings are displayed for all sensors, battery supply, motor power, and voltage converters. Bullet connectors enable the power board to be interchangeable and allow compatibility with other power boards for easy vehicle modification. Six digital meters are used to display system voltages. The first five meters continuously display the most critical system voltages, which are: system battery, right drive motor, left drive motor, pre-fused 24v to 24v, and pre-fused 24v to 12v regulated supplies. The sixth meter is connected through a rotary switch to the following eight post-fused components: camera, laser rangefinder, GPS, compass, computer, RC power, Remote E-Stop System, and the wireless router. This innovation provides critical health and diagnostic feedback that is especially important given the added complexity and higher vibrational loads expected in the 19th IGVC.

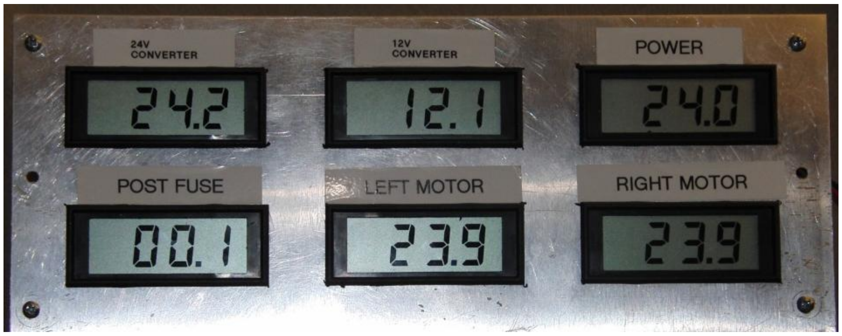


Figure 3.1: Voltage Health Monitoring System

3.2 Memory Foam Electronics Suspension

The Reagle IV team decided that not only did the chassis require vibration damping, but also the electrical box. Interruptions due to electrical components or connections being jarred loose were a frequent occurrence when running previous non-suspension vehicles at high speed. The memory foam suspension used specifically for the electronics box, allows Reagle IV to operate more reliably, and the lifespan of components are expected to increase. The stiffness of the shock absorption material was adjusted by changing the thickness of foam until rapid settling was observed after a disturbance.

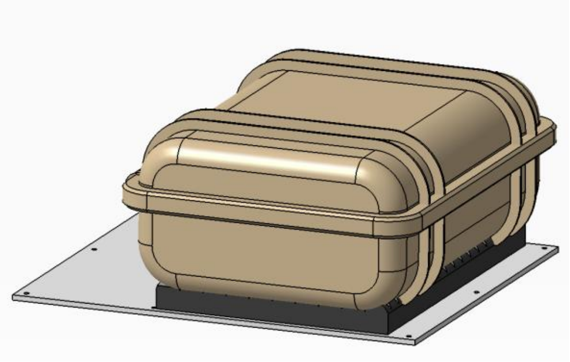


Figure 3.2: Electronic Suspension Memory Foam

3.3 ReagleLift Pro

A problem that many teams encounter throughout development and competition is attempting to test the vehicle in a stationary position. It is inefficient and potentially dangerous to repeatedly have someone lift up the vehicle and place a cinderblock or solid structure underneath, so that the power driven wheels are lifted off the ground. This is where our team's initial design of ReagleLift proved itself. It provided the ability to lift up the drive wheels for motor testing, and it aided transporting the if it became inoperable.

Figure 3.3: ReagleLift Pro

This year with the redesign of Reagle's drivetrain, a new and more effective design of ReagleLift has been created, now named ReagleLift Pro. It uses a similar U-channel beam to grab the rear axle of the vehicle, but it is now pin connected so it can freely rotate. Now when turning the vehicle, ReagleLift Pro allows the front caster wheel of Reagle IV to act as a pivot point. This enables the vehicle be turned in to the correct direction and transported with far less effort. The placement of the U-channel beam has also been raised vertically above the axle on ReagleLift Pro, creating an over-dead-center mechanism that locks the vehicle in the raised position.

Figure 3.4: ReagleLift Pro Swivel View

4 MECHANICAL SYSTEM

Reagle IV's chassis was redesigned last year be lighter and stiffer than the original chassis. Two electric motors on the bottom of the frame are arranged in a differential drivetrain system. Mounted on the shafts of the motors is the new addition to the frame, the trailing arm suspension. The suspension was agreed upon by the team to be the best solution to enhance performance with the increase in speed limit in the 2011 IGVC rules. Also new is a rear mounted rack, which helps distribute more weight to the rear drive wheels while adding a lower location to place the required 20 lb payload. Last year, the payload was on a mast-mounted shelf that contributed to a high center of gravity

4.1 Vehicle Chassis

Reagle's chassis is made from 1 inch 6061 aluminum alloy square tubing with 1/8 inch wall thickness. Three 1/8 inch plates on different levels in the frame hold all of the electronics, the motor assembly and the sensory equipment on board. The chassis measures 44 inches long by 33 inches wide by

17 inches tall (excluding mast) with a ground clearance of 4 inches. Reagle weighs 150 pounds without the payload. Side covers made of 1/16 inch aluminum plating protect interior components.

Attached to the motor shafts is the newly added trailing arm suspension. As shown in figure 4.1, it consists of a rear swing arms pivoted about the axis of the drive motors. A Fox Vanilla R coil spring over oil damper shock absorber links the trailing arm to the back of the frame. An ANSI #35 chain transfers power from 30 tooth sprockets on the gearhead shafts to 20 tooth rear sprockets bolted to 16 inch composite wheels. This new suspension system reduces vibrations on rough terrain. Weight distribution was maintained at 60% in the rear by transferring weight to the rear payload rack, keeping excellent traction. By placing more weight closer to the ground in the lower shelf and rear rack, vehicle maneuverability and high-speed turn stability is increased.

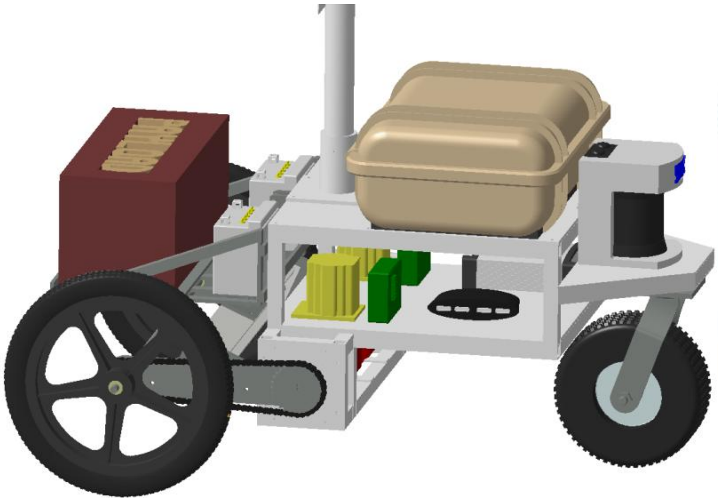


Figure 4.1: Vehicle Chassis

Figure 4.2: Quicksilver SilverMax 34HC-1 Motors

4.2 Vehicle Drivetrain

Reagle IV uses a differential drivetrain. The components of the drivetrain consist of two Quicksilver Control SilverMax 34HC-1 brushless DC servomotors mounted on the underside of the bottom plate on Reagle IV, two Silvernugget N3 motor controllers, and two motor locks. The electric motors are geared down to a 10:1 ratio with NEMA 34 single-stage planetary gear heads affixed to each. There is a free-spinning 10 inch caster wheel at the front of the vehicle that allows the vehicle to execute zero radius turns. The 30 teeth front sprocket to 20 teeth rear sprocket steps the gear ratio up by 2:3, so the combined gear ratio is 20:3. This gearing allows the vehicle to achieve top speeds of approximately 9 miles per hour.

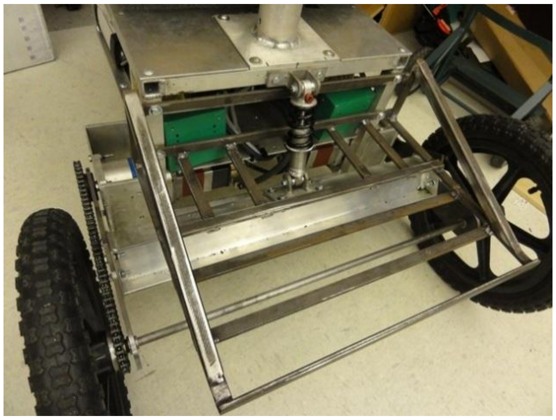


Figure 4.3: Drive Train and Rear Rack

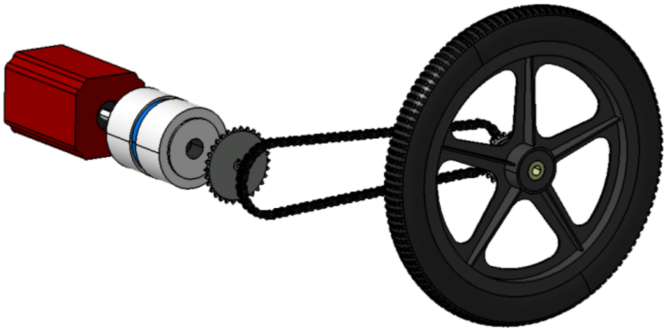


Figure 4.4: Exploded View of Drive Train

5 ELECTRICAL SYSTEM

5.1 Power System

Reagle is powered by two 12V MagnaPower ETX16L AGM 19 amp hr batteries connected in series. These lead acid batteries provide an economic and reliable power source for all of Reagle's components, providing typical run times of almost an hour. A cover protects the terminals from shorting or getting wet, which is especially important since the batteries are placed on the rear rack and are exposed to the elements.

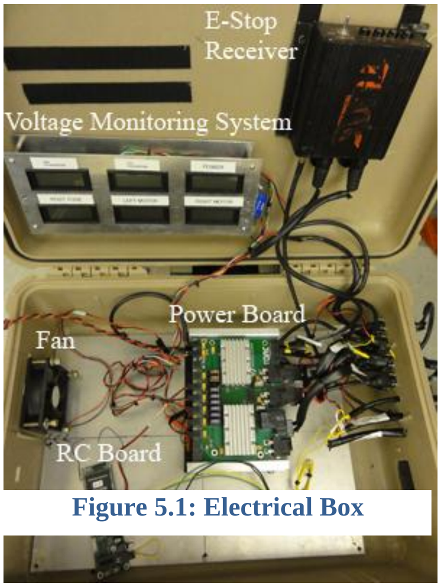


Figure 5.1: Electrical Box

5.2 Power distribution

The central hub of Reagle's power system is a custom developed power board shown in figure 5.1. The board, E-stop receiver, remote control board, and voltage monitoring system are safely stored within a weather resistant 1520 Pelican case. Unregulated 24V power flows from the batteries to two DC-to-DC regulators located on the power board: one outputs 24V regulated voltage, and the other outputs 12V regulated voltage.

The regulated 24 volts is distributed to the Laser Range Finder (LRF) and to an APlus B-20 ruggedized computer. The regulated 12 volts is sent to the compass, GPS, camera, and to two auxiliary 12 volt connectors. Each of these connectors has an individual fuse to avoid damage from a power surge.

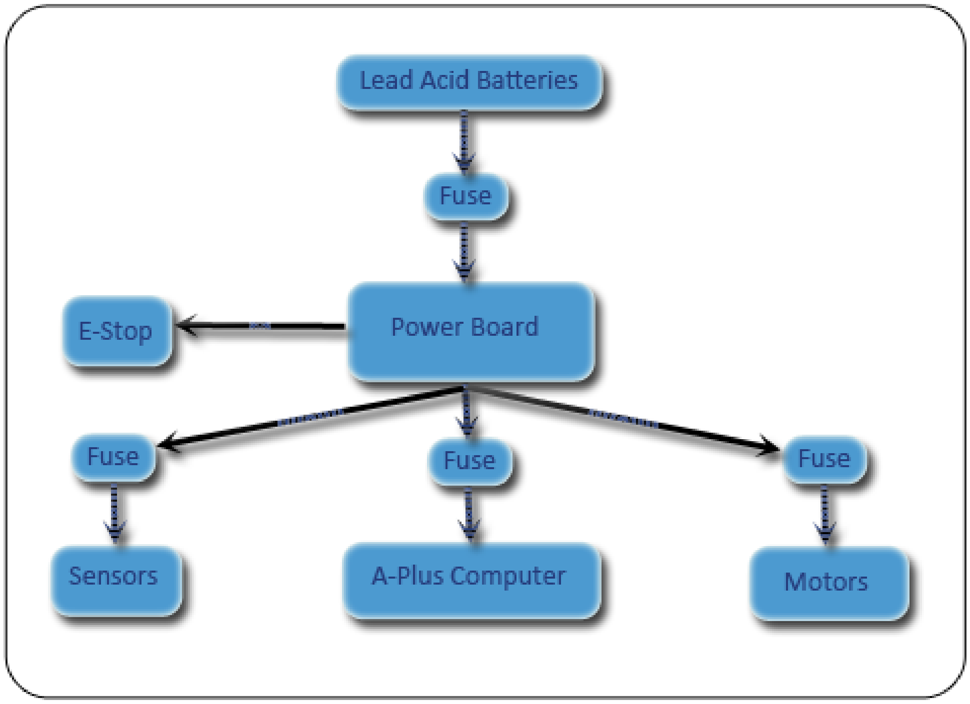


Figure 5.2: Power Distribution Flow Chart

5.3 Emergency Stop System and Safely Strobe Light

Reagle IV incorporates the SafeStop emergency stop system from TORC Technologies shown in Figure 5.3. The SafeStop transmitter uses spread spectrum frequency hopping for decreased interference and reliable transmission of up to 6 miles. The battery can lasts 30 hours on a single charge. As implemented, the SafeStop system provides both a pause mode, which rapidly brings the vehicle to a controlled stop without cutting power, and a "hard" emergency stop that opens a relay, disengaging all electrical power. A separate radio controlled transmitter is used to drive the vehicle in non-autonomous mode. Reagle IV is also equipped with a strobe light that indicates to bystanders when Reagle IV is under autonomous control.

Figure 5.3: TORC Technologies SafeStop Transmitter and Receiver

5.4 Power Consumption

Reagle was designed with efficient use of power in mind. The motors require less than 400 watts of power, while the compact A-Plus computer draws only 200 watts of power. Table 5.1 shows the power requirements of each component in the electrical system.

Component	Voltage (V)	Current (A)	Power (W)
Motors/Encoders	24		384.0
A-Plus Computer	24	7	168
Laser Range Finder	24	1.8	43.2
Camera	12	1	12
DGPS	12	0.35	4.2
Digital Compass	12	0.02	0.24
Total Consumption			611.6

Table 5.1: Power Consumption

5.5 Sensor System and Data Integration

Reagle uses four commercial-off-the-shelf (COTS) sensors as shown in figure 5.4 below. The central point of integration is an APlus Mobile B-20 Rugged PC with Core 2 Duo 2.8 Ghz processors, 8 GB RAM, and 40 GB solid state hard drive. The LabVIEW programming environment installed on the APlus is the central point of software integration. LabVIEW is a critical tool used to receive and organize data from the sensors, and then make the necessary decisions. The APlus is accessed by laptop via an onboard wireless connection.

LRF — Sick's LMS 291- Laser Range Finder scans for obstacles in a 180° planar sweep in 1° increments at 25 Hz. The maximum sensing rage is 80 m, but Reagle limits detection to obstacles within 3 m. Time-of-flight technology is used to calculate the distance to an object from the vehicle. This sensor scans in front of the vehicle and is used for obstacle detection and avoidance algorithms. The LIDAR collects angle and distance information of obstacles over the entire 180° plane and transmits this data to the APlus via an RS-232 serial connector and serial-to-USB converter.

DGPS — Novatel's ProPak-LB Differential GPS, used in tandem with a Novatel GPS 702 GGL antenna, combines global positioning satellites with the OmniSTAR HP correctional service. The DGPS is used in the Navigation Challenge to determine vehicle position. The DGPS collects GPS coordinates at 20 Hz and transmits this data to the APlus via an RS-232 serial connector and serial-to-USB converter.

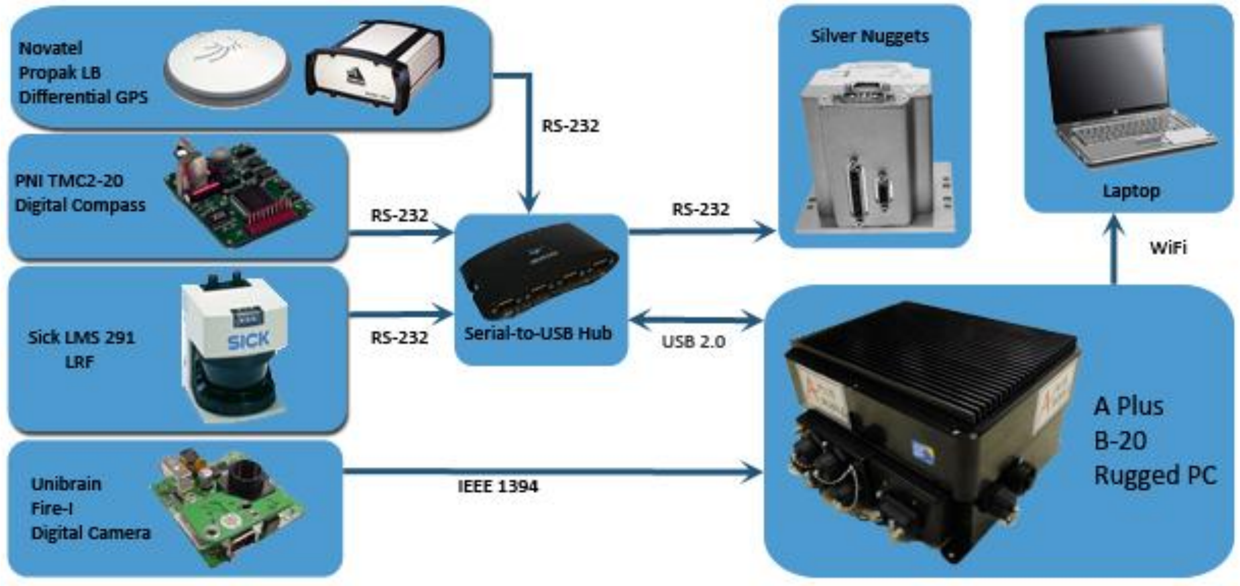


Figure 5.4: Sensor Integration Flow Chart

Digital Compass — Pacific Navigation Instrument's TCM2-20 digital compass detects the earth's magnetic field and determines the vehicle's heading relative to magnetic north. The compass is a three-axis, tilt compensated instrument and is used in the Navigation Challenge to determine vehicle heading. It has a heading accuracy of 0.5° when level and 1.0° when tilted. The compass collects heading and tilt information at up to 30 Hz and transmit this data to the Mac Mini via an RS-232 serial connector and serial-to-USB converter.

Digital Camera — The Unibrain Fire-i Board IEEE 1394 firewire camera captures images used for line detection algorithms in the Autonomous Challenge. It has a native resolution of 640x480 at a frame rate of 15 fps and 94° diagonal field of view. A weatherproof housing was constructed to enclose the camera, and an anti-glare filter reduces the impact of reflective light. Data is transmitted to the Mac Mini via an IEEE 1394 firewire cable.

6 SOFTWARE SYSTEM

The software for Reagle IV was developed using National Instruments LABVIEW. This graphical programming environment allows the user to operate Reagle simply and efficiently.

6.1 Software Structure

LABVIEW provides an intuitive Graphical User Interface (GUI) to allow the user to modify the software before it is run. The GUI is also used to verify that all components are fully operational before the user begins the autonomous program. Sensors have individual channels and data is collected simultaneously. Reagle's process cycles continuously at approximately 9 Hz during operation. For safety, a short lag will occur for any remaining persons to move clear before operation begins.

6.2 Obstacle Avoidance

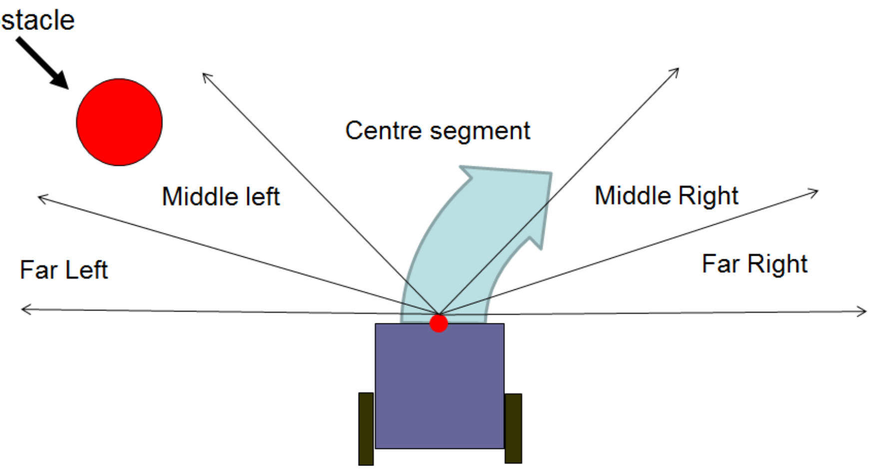


Figure 6.1: Obstacle Avoidance Criteria

The Laser Range Finder (LRF) provides information which allows for the obstacle avoidance algorithm to be used while recording the position and distances of obstacles in its path. The obstacle avoidance algorithm first finds each obstacle and its relative position and distance from the vehicle. Then, it calculates different paths around the obstacles and gives each a 'cost'. The lowest cost is chosen to be the most suitable path for the vehicle to travel. The cost is dependent on factors such as distance of closest obstacle, displacement of the obstacle from the center of the vehicle, deviation of the path from the required heading, and deviation from the last chosen heading. In the Autonomous Challenge, the final vehicle heading considers both the obstacle avoidance heading as well as the vision derived heading. Figure 6.2 shows the obstacle avoidance algorithm.

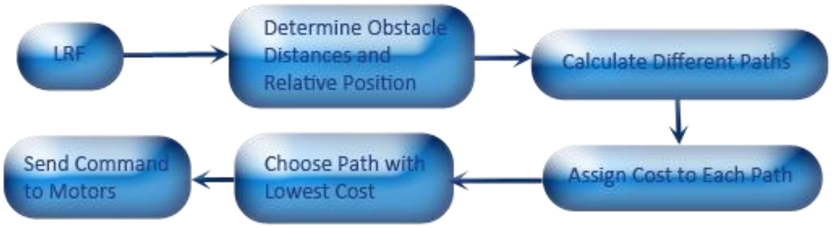


Figure 6.2: Obstacle Avoidance Algorithm

The final commanded path is a circular arc which is chosen to provide Reagle a continuous fluid motion. The radius of the circular arc is calculated using the difference in wheel speeds. The wheel speeds are controlled to accurately move Reagle IV.

Consider an example of a dead end with only one way out (the way the vehicle entered). As the vehicle approached the dead end, it would detect it as a center segment obstacle and calculate paths to the right or left of the obstacle. At the same time, it will slow down proportionately as distance to the obstacle decreases. The algorithm will consider whether there are obstacles on each side of the dead end and also assign a lower cost to the direction of the desired heading. As the vehicle selects a direction and begins turning, it will still see the obstacle, since a dead end surrounds the vehicle on three sides. All else being equal, the next priority is to assign the lower cost to the direction of the last chosen heading, so if the vehicle is turning right, it will continue right, and if it is turning left, it will continue left. Reagle is able to make zero radius turns, so it will not hit an obstacle by virtue of making a wide turn. Once Reagle is almost facing the direction it came, it will see obstacles in the left and right segments but none ahead, and so its path will be to continue until it leaves the dead end area.

6.3 Autonomous Challenge Algorithm

The LRF's obstacle avoidance algorithm as described above is used simultaneously with the compass and computer vision algorithm described in sections 6.3.1 and 6.3.2 below to complete the Autonomous Challenge.

6.3.1 Detection of Lines

The following flow diagram, figure 6.3, illustrates the primary steps in the computer vision algorithm. During image processing, the acquired image is first separated into red, green, and blue color planes. The white and yellow boundary lines are then recombined in a weighted average while suppressing background information. To reduce processing time, the acquired RGB image is converted to grayscale and down sampled to a resolution of 160x120. After this, the image is split into the vehicle's left and right side views. To define the dominant line in each side view, the image is then scanned for the brightest pixels, and a Hough transform is used and a decision tree is used to determine the correct heading depending on situational line detection cases.

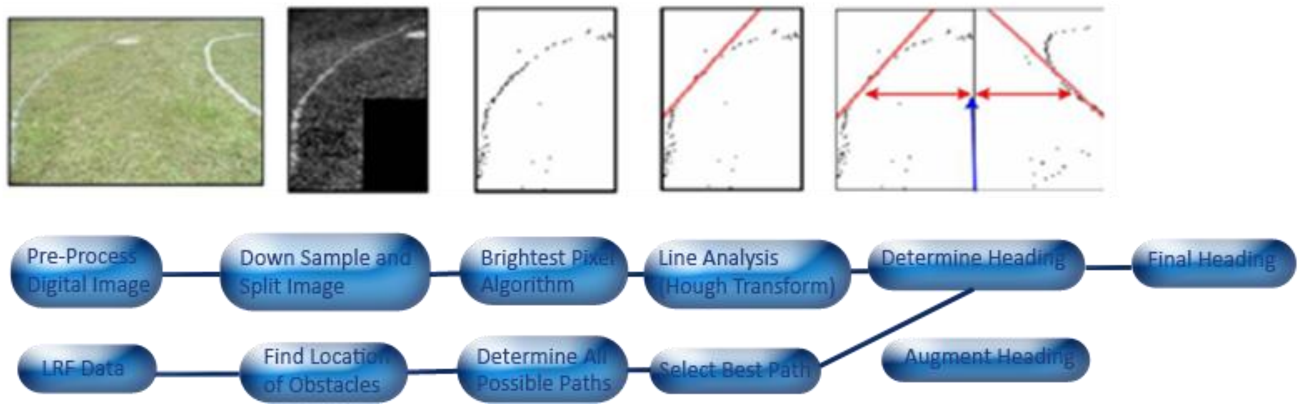
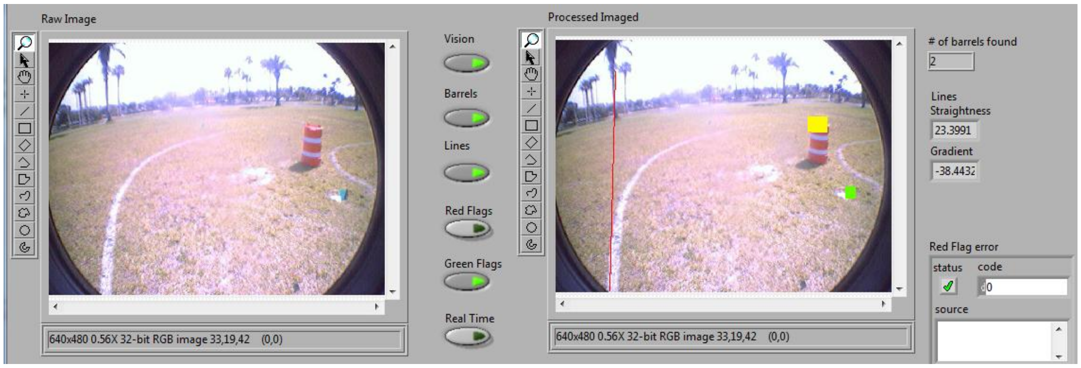


Figure 6.3: Autonomous Challenge Algorithm

6.3.2 Detection of Flags

This year, green and red flags were added to the aotunomous chellenge course. To detect these flags, LabVIEW’s Vision Assistant Express is used. The express also located barrels and white lines as shown in figure 6.4.



640x480 0.56X 32-bit RGB image 33,19,42 (0,0)

640x480 0.56X 32-bit RGB image 33,19,42 (0,0)

# of barrels found: 2

Lines Straightness: 23.3991

Gradient: -38.4432

Red Flag error

status: ✓

code: 0

source:

Figure 6.4: Vision Assistant displaying the location of a green flag

6.4 Navigation Challenge Algorithm

Reagle takes on the challenge of navigation with a combination of three devices; a Novatel differential GPS, a Pacific Naviagion Instruments TCM2-20 3-axis digital compass, and a SICK LMS-291 laser range finder. Reagle navigates to different locations using the GPS to set up waypoints. Reagle uses the laser range finder to detect the number of obstacles and their location relative to the vehicle. It then uses the algorithm shown in figure 6.4 to turn Reagle to the side with fewer obstacles.

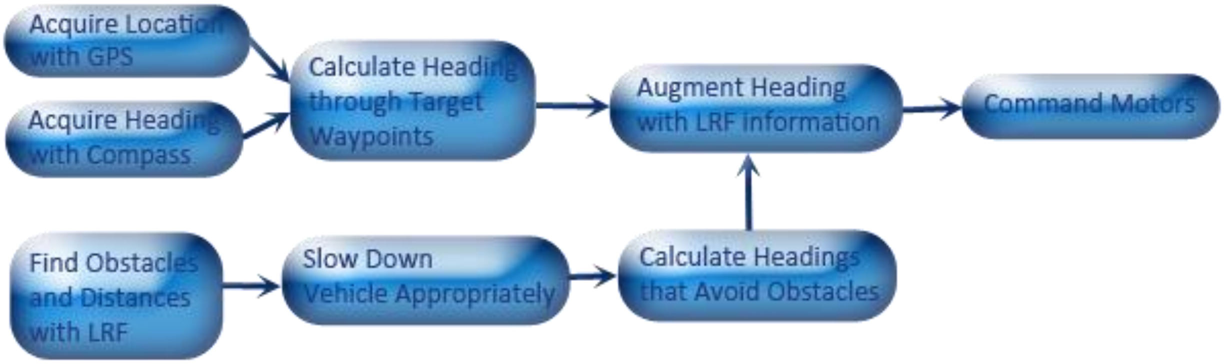
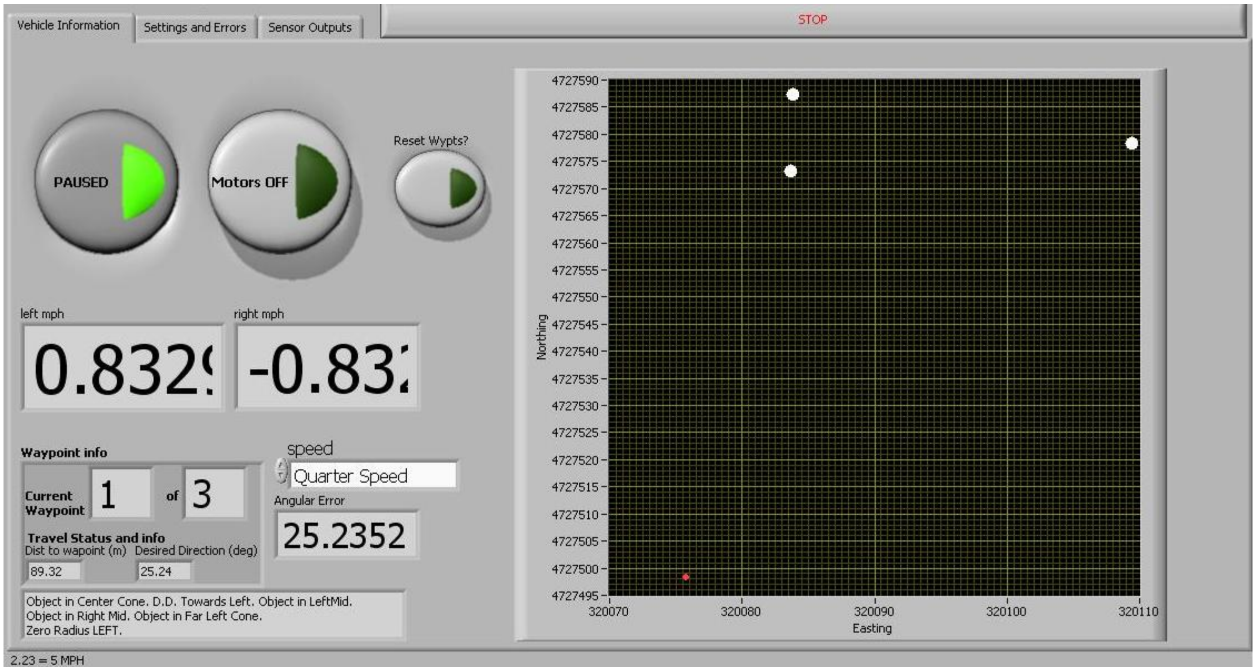


Figure 6.5: Navigation Challenge Algorithm

The figure below shows the navigation code’s LABVIEW frontpanel. The red dot represents Reagle’s current position while the white dots represent the target waypoints.



left mph
0.832

right mph
-0.83

Waypoint info

Current Waypoint 1 of 3

speed
Quarter Speed

Angular Error
25.2352

Travel Status and info

Dist to wapoint (m)
89.32

Desired Direction (deg)
25.24

Object in Center Cone. D.D. Towards Left. Object in LeftMid.
Object in Right Mid. Object in Far Left Cone.
Zero Radius LEFT.

2.23 = 5 MPH

Figure 6.6: LABVIEW Front Panel

6.5 JAUS Challenge

The Joint Architecture for Unmanned Systems (JAUS) is an SAE standardized communication protocol that has been implemented on Reagle IV. This software requires a sequence structure, which creates a timeline of events. The first event opens the port and UDP connection to the controlling unit. Reagle IV then broadcasts a Query Identification every 5 seconds. Once the control unit responds, the next sequence is started.

The second event parses, sends and receives JAUS messages. Reagle IV receives messages faster than it can process the messages. Even so, all of the messages are processed in the order of reception and placed into an event queue. Once the message is removed from the queue, the first action required is to determine the validity of the messages by checking the origination identity, as well as the sequence number to ensure messages being received only once. Once a message is determined to be valid, the message identity is determined and the remaining message data is handled appropriately. Responses are placed into another event queue, sequenced into a header and trailer, and sent to the control unit.

7 PREDICTED PERFORMANCE AND TESTING

7.1 Speed

The two Silvermax 34HC-1 motors have a no-load maximum speed of 3000 RPM. With the 20:3 combined gear ratio, this becomes 450 RPM. With 16 inch drive wheels, the theoretical maximum speed is 21.4 mph. In testing, with RC control, the maximum speed achieved was 12 mph. The maximum operating speed is software limited to 210 RPM (10 mph), in accordance with IGVC regulations.

7.2 Ramp Climbing Ability

It can be derived that the maximum theoretical slope Reagle IV can climb is $\theta = \sin^{-1}({}^{\tau}/_{rW}) = 12.7°$, where τ is Reagle's stall torque (281 in-lb), r is Reagles drive wheel radius (8 inches), and W is Reagle's weight (170 lb with payload). This exceeds the maximum slope that will be encountered on the course, 15% grade (8.53°), by about 50%. In actual testing, Reagle IV was about to climb slopes of 10°.

7.3 Waypoint Accuracy

The GPS system has an accuracy of 0.25 meters Circular Error Probable (CEP) using CDGPS (Canada-wide Differential Global Positioning System), as well as a frequency of 20 Hz. At 10 mph, Reagle can move 0.22 m in 1/20th of a second, so positional accuracy is less than half a meter, which is well within the waypoint radius of 1-2 m.

7.4 Reaction Times

Since the maximum incline on the course will be a 15% grade, the maximum height of a ramp that is 3 m long is 0.45 m (18 inches). The LRF is mounted 16 inches above the ground, which should avoid detecting hills and ramps as obstacles in almost all cases.

All four sensors operate faster than the process rate of Reagle's software, so there will be no problems getting accurate sensor information.

Latency		
Process		Time (ms)
Image Acquisition		67
Vision	Preprocessing	2
	Thresholding	0.4
	Hough Transform	12
	Heading Determination	< 1
	Total	14.4
Obstacle Avoidance		24
Total		105

Figure 7.1: Autonomous Challenge Algorithm Latency

7.5 Battery Life

The two 12V MagnaPower AGM sealed batteries that power Reagle IV have a capacity of 19 amp hours, which means that both batteries in series provide 24 volts and 456 watt-hours of power before falling to 21 volts, at which point they can no longer reliably power the vehicle. Assuming a maximum load power consumption of 611 watts, the vehicle can be powered for 45 minutes before needing a recharge. Safety was a big factor in battery selection, and AGM batteries are sealed and spillproof, greatly reducing the change of explosion. Since the batteries are operated outside

Figure 7.2: MagnaPower AGM Batteries

of the chassis, custom made terminal covers were made to prevent exposed metal terminals.

8 REAGLE IV VEHICLE COST

The table below shows a cost analysis of Reagle IV showing the cost of each component and breaks it down into two categories.

Reagle Component	Quantity	Retail Cost	Team Cost	Percentage Saved
Sensors & Electrical				
A Plus Computer	*1*	*$30,000.00*	*$0.00*	*100%*
Novatel Smart Antenna	*1*	*$5,000.00*	*$1,500.00*	*70%*
Sick LMS-221 Scanning Laser Range Finder	*1*	*$5,930.00*	*$5,930.00*	*0%*
Unibrain Fire wire Digital Camera	*1*	*$82.00*	*$82.00*	*0%*
PNI TCM2-20 Digital Compass	*1*	*$700.00*	*$0.00*	*100%*
National Instruments RS-232 Serial to USB Converters	*1*	*$200.00*	*$200.00*	*0%*
TORC Power Distribution Board	*1*	*Donated*	*Donated*	-
TORC Remote Control Board	*1*	*Donated*	*Donated*	-
Voltage Meter	*1*	*$214.00*	*$214.00*	*0%*
Wire, Connecters, and miscellaneous components	-	*$743.00*	*$743.00*	*0%*
Sensors & Electrical Subtotal:		***$42,869.00***	***$8,669.00***	***34%***
Mechanical				
Quicksilver DC Brushless Motors	*2*	*$2,450.00*	*$2,450.00*	*0%*
Caster Wheel	*1*	*$25.00*	*$25.00*	*0%*
Aluminum Frame	-	*$75.00*	*$75.00*	*0%*
Glenair Electronic Component Connectors	*1*	*Donated*	*Donated*	-
Pelican Case	*1*	*$112.00*	*$112.00*	*0%*
Trailing Arm Suspension	-	*$507.00*	*$507.00*	*0%*
Low Rolling Resistance Composite Nylon Wheels	*2*	*$0.00*	*$0.00*	-
Reagle Lift Pro	-	*$50.00*	*$50.00*	*0%*
Mechanical Subtotal:		***$3,219.00***	***$3,219.00***	***0%***
	Total:	**$46,088.00**	**$11,888.00**	**27%**

Table 8.1: Vehicle Costs

9 CONCLUSION

Reagle IV is based on a reliable legacy vehicle platform, but it incorporates substantial improvements in hardware and software that will allow it to meet all challenges of the 2011 Intelligent Ground Vehicle Competition. With the addition of new “delighter” innovative features and based on extensive testing, we believe Reagle IV will provide an adaptable and reliable platform for this and future competitions.