EMBRY-RIDDLE
AERONAUTICAL UNIVERSITY

Presents

ALVIN

Team members:

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

1 INTRODUCTION

ALVIN is an Autonomous, three wheeled, differentially-steered, Land robotic Vehicle used for Intelligent Navigation. ALVIN's design incorporates mechanical, software, and electrical reliability, accessibility, and maintainability. The software algorithms from its predecessor, Reagle V, have been modified with additional algorithms and optimized to handle the challenges of the basic and advance courses.

2 DESIGN PROCESS

The development of ALVIN uses a seven step design process that began with determining the problem presented by the competition. For the IGVC competition, the problem is to make a robot that can successfully navigate through an obstacle course to set waypoints. The customers are the IGVC competition judges, the professors, and future team members. With those customers in mind, new specifications were set this year to not only meet the new minimum standards, but also to improve upon the previous year's platform.

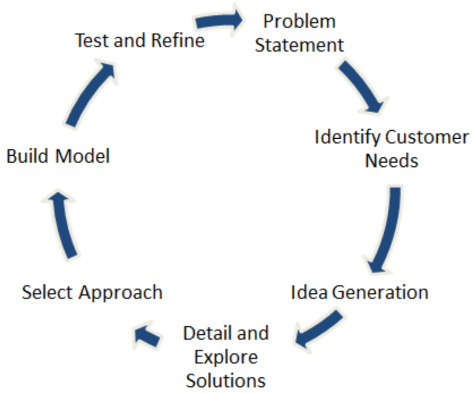
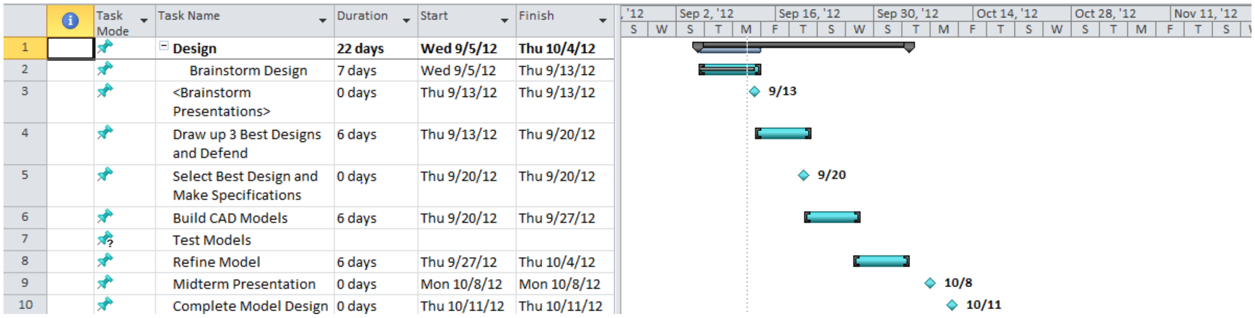


Figure 1 Design Methodology

The customer's requirements, functional requirements, preferences, and comparisons with competitors were identified using a House of Quality and system interfaces were mapped using CORE. CORE is a system engineering program used to define top level requirements and visually display dependencies and links with subsystems, elements, definitions, items, and interfaces. Following the HoQ and top level diagram, the mechanical team focused on brainstorming. The mechanical team members were tasked with developing and presenting their CAD designs. Each design was scored based on selected criteria, and the design with the highest score was selected.

The software team generated a task list with ranked priorities (1-10, highest-lowest), identifying the problems and solutions that required testing.

Through an iterative process of selecting an approach, testing, and refining, the algorithms that will perform at competition have been thoroughly evaluated to ensure they will meet the demands of the competition course. To make certain that changes were implemented in a timely manner, a Gantt chart was used to create a timeline of expected progress and milestones. These goals were checked weekly and adjustments were made accordingly.



	Task Mode	Task Name	Duration	Start	Finish
1		**Design**	**22 days**	**Wed 9/5/12**	**Thu 10/4/12**
2		Brainstorm Design	7 days	Wed 9/5/12	Thu 9/13/12
3		<Brainstorm Presentations>	0 days	Thu 9/13/12	Thu 9/13/12
4		Draw up 3 Best Designs and Defend	6 days	Thu 9/13/12	Thu 9/20/12
5		Select Best Design and Make Specifications	0 days	Thu 9/20/12	Thu 9/20/12
6		Build CAD Models	6 days	Thu 9/20/12	Thu 9/27/12
7		Test Models			
8		Refine Model	6 days	Thu 9/27/12	Thu 10/4/12
9		Midterm Presentation	0 days	Mon 10/8/12	Mon 10/8/12
10		Complete Model Design	0 days	Thu 10/11/12	Thu 10/11/12

Figure 2 Design Section of Gantt Chart

2.1 Improvements

Below is a summary of major changes this year; each is discussed in more detail in its respective section.

- Mechanical: Payload and battery cage, shelving for easy accessibility to electronics and face-level computer
- Electrical: Entire vehicle rewired and new connectors installed
- New Sensors:
  - Ambient Light Sensor
  - GEDC-6 Sparton Compass
  - Two GoPro cameras for Dual-Vision
  - Two SICK LMS 291 LRFs for Dual-Vision
  - Ultrasonic Sensors
- Software:
  - Optimized autonomous and navigation code
  - Refined flag detection algorithm
  - New dead end algorithm based on Dual-Vision
  - Refined line detection and obstacle avoidance algorithms
  - Visual Distortion Correction and Real-World Coordinate System

2.2 Innovations

Ambient Light Sensor

The ambient light sensor is used to detect changes in the external light level. The sensor automatically changes the image threshold while the robot is in use to detect certain colors in objects. This accounts for the changes in light due to being either inside, outside, or from weather changes. The ambient light sensor takes in light and outputs a current signal that is connected into a DAQ to send the output data into the threshold code in LabVIEW.

Dual-Vision System

One of the biggest weaknesses with previous IGVC robots is the limited field of view that restricts planning in complex obstacle situations. ALVIN's new design features the addition of a second SICK Laser Range Finder (LRF), allowing for Dual-Vision for intelligent forward and backwards driving of the robot. The LRF is accompanied by a second GoPro camera for error correction in obstacle detection. This expanded field of view allows ALVIN to maneuver more efficiently out of dead ends, or around potential obstacles surrounding waypoints on the field.

SPARTON GEDC-6 Compass

ALVIN uses the Sparton GEDC-6 digital compass for navigation. The compass measures heading, pitch, and roll and provides the information to the robot so it can adjust its position. ALVIN accesses the orientation data at 20 Hz via RS-232 and a serial-to-USB converter. As opposed to the SP3004D digital compass used in the previous version of the robot, the GEDC-6 reduces the effects of magnetic disturbances and variations that affect heading outputs and provides a True North output.

Tool Compartment Shelf

The design includes a tool shelf to store tools needed to maintain, adjust, or repair the robot. The tool shelf increases the duration of the vehicle's reliability on and off the field while integrating convenience and availability of tools for the customer.

2.3 Vehicle Cost

Table 1: ALVIN costs

ALVIN Component	Quantity	Retail Cost	Team Cost
Sensors & Electrical			
DELL Latitude Laptop Computer	*1*	*$780.00*	*$0.00*
Novatel SPAN DGPS and Antenna	*1*	*$25,000.00*	*$0.00*
Sick LMS-291 Scanning Laser Range Finder	*2*	*$11,860.00*	*$0.00*
GoPro HD Hero Camera *(new)*	*2*	*$400.00*	*$133.00*
Sparton GEDC-6 Digital Compass *(new)*	*1*	*$1,350.00*	*$0.00*
Gearmo RS-232 Serial to USB Converters	*2*	*$88.00*	*$88.00*
Custom In-House Power Distribution Board	*1*	*$500.00*	*$0.00*
Torc SafeStop ES-220 Wireless E-Stop System	*1*	*$2,000.00*	*$0.00*
AGM Lead Acid Batteries	*2*	*$195.00*	*$195.00*
Wire, Connecters, and miscellaneous components *(new)*	-	*$900.00*	*$100.00*
Vishay Ambient Light Sensor	*1*	*$0.67*	*$0.67*
Maxbotics LV-EZ3 Ultrasonic Sensors	*2*	*$60.00*	*$60.00*
Sensors & Electrical Subtotal:		***$43,136.67***	***$576.67***
Mechanical			
Quicksilver DC Brushless Motors	*2*	*$2,450.00*	*$0.00*
Aluminum Frame	-	*$507.33*	*$157.33*
Trailing Arm Suspension	-	*$600.00*	*$15.00*
Low Rolling Resistance Composite Nylon Wheels	*2*	*$0.00*	*$0.00*
Caster Wheel	*1*	*$25.00*	*$25.00*
Polycarbonate and Acrylic Panels	*1*	*$139.08*	*$139.08*
Mechanical Subtotal:		***$3,721.41***	***$336.41***
	Total:	**$46,857.41**	**$915.41**

2.4 Team Organization

Areas of Concentration							
Team Member	Academic Major	Mechanical	Software	Electrical	Document	CAD	Hours
Alecia Hurst (Lead, Software Lead)	M.S. Mechanical Engineering	x	x	x	x		702
Matt Greene (Mech Lead)	Mechanical Engineering	x			x	x	350
Marco Schoener	Mechanical Engineering	x	x				323
Matt Standifer (Design Lead)	Mechanical Engineering	x				x	303
Abby Butka	Still Exploring		x	x			250
Jacky Qi	Aerospace Engineering	x	x				310
Jacob Maher	Mechanical Engineering	x					150
Total							2388

3 MECHANICAL

3.1 Vehicle Chassis

ALVIN's design focuses on improving the accessibility of its components. The frame consists of three parts: the tower case, payload and battery cages, and tool box shelf. Each of these parts is easily accessed by the user. This improved accessibility makes the robot easy to maintain as individual components are easily removed, fixed or replaced without having to alter the rest of the chassis.

3.1.1 Tower Case

The tower case sits on top of the 7073 aluminum, .25" thick base plate lined with beam support to prevent deflection. With the dimensions 4 feet in height, 2 feet in width, and 1 foot in depth, the tower consists of 80-20 Aluminum beams connected together by L-brackets. The 80-20 and L-brackets are easily adjustable while simultaneously providing structural support to hold all the electrical components inside of it. Acrylic covers the tower's exterior to keep the interior of the robot dry as well as providing good visibility to the interior of the robot. Inside the tower there are two shelves. Both are easily adjusted up and down and have a sheet of polycarbonate for the electronics to mount to. The adjustable shelves extend the life of the robot by enabling it to evolve as new components need to be put in or replaced. .

3.1.2 Battery and Payload Cage

The battery cage and payload cage are designed to specifically fit either one of the two batteries and the payload, respectively. Each battery cage is built with aluminum square tubing and bolted to the payload cage and the base plat of the robot. The exterior of the cage is covered in acrylic to provide splash shielding (Figure 4). The battery does not need to be kept completely dry and therefore the sealing of the cages compared to the tower is not as crucial. The battery is strapped down with velcro to prevent movement inside the cage. The front piece of acrylic is attached with velcro and allows the user easy access to the batteries. The payload cage is also made of aluminum square tubing and is slightly larger than the dimensions of the payload itself. This tolerance allows for varying sizes of payloads. The cage is bolted to the base plate as well as having two steel plates 1/8 in thick bolted to the top (Figure 3). These steel plates support the two Laser Range Finders (LRFs).

Figure 4 Right side battery cage with battery inside

Figure 3 Payload cage in the middle with battery cage on either side. LRF on top of steel plate.

The beam is bolted to the payload cage (Figures 3,4). The final assembly of the battery and payload is connected to the base plate with bolts and supports two LRFs on top as well as electronic connectors (Figure 4).

3.1.3 Tool Shelf

Below the base is a thin aluminum plate attached to the chassis of the robot that is intended for use as a tool shelf. The tool box that goes on the shelf contains but is not limited to: Screwdrivers of various sizes, allen wrenches of various sizes, socket wrench with 1/4 head, and wrench. This set of tools is sufficient to perform most servicing operations on the robot.

3.2 Drivetrain

ALVIN's drivetrain (Fig. 5) consists of two Quicksilver SilverMax 34HC-1 brushless motors. Attached to these motors are NEMA 34 single-stage planetary gear heads. These gear heads transfer more torque from the motors directly to the wheels with a gear ratio of 10:1. A #35 ANSI chain transfers power between two sprockets with an equal number of teeth.

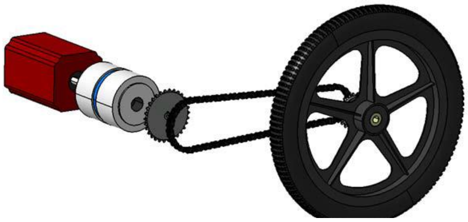


Figure 5 ALVIN's Drivetrain

3.3 Suspension System

ALVIN's suspension system, like its predecessor REAGLE V, is a trailing arm system. One problem that ALVIN's predecessor had in previous years is that the trailing arm rested directly on the sprocket attached to the gearhead, which transferred a considerable amount of stress. As a result, the gearhead shaft sheared on multiple occasions, and friction increased the required torque from the motors. To resolve this problem the sprocket now rests on a bronze bushing mounted directly on the chassis, greatly reducing the stress to the gearhead. In addition, ALVIN's maneuverability is increased due to the shorter moment arm from drive shaft to caster wheel, the decreased axle length, as well as the increased rear weight distribution.

4 ELECTRICAL SYSTEM

4.1 Power System and Battery Life

ALVIN is powered by two 12V MagnaPower ETX16L AGM batteries connected in series, which provides a nominal 24V to the system. These lead acid batteries provide an economic and reliable power source for all of ALVIN's components. . The two batteries (Fig. 5) have a total capacity of 19 Ahr. Assuming a typical load power consumption of 240 watts, as shown in Table 3, the vehicle can be powered for almost 2 hours before needing a recharge. During testing, ALVIN is only run for an hour before recharging to protect the health of the batteries.

Safety was a big factor in battery selection, and AGM batteries are sealed and spillproof. Since the batteries are located outside of the chassis, custom terminal covers were made to prevent exposed metal terminals. For additional protection from the environment, the batteries are placed in cages with removable doors.

4.2 Power Distribution

Figure 6 Power distribution flow chart

The central hub of ALVIN's power system is a custom developed power board. Unregulated 24V power flows from the batteries to the power board, which can provide regulated 24V, 12V, 5V, and 3.3V to the sensors.

The regulated 24 volts is distributed to two Sick Laser Range Finders (LRFs). The regulated 12 volts is sent to the GPS, SafeStop, and LEDs. The regulated 3.3 volts is sent to the ambient light sensor and Sparton GEDC-6 compass. The regulated 5 volts is not be currently used since each ultrasonic sensor is powered by an individual 5V battery but is available for testing future sensors and electrical system expansion. Each of these connectors has an individual fuse to avoid damage from a power surge or short circuit. Figure 5 shows how power is distributed in the system.

4.3 Power Consumption

Table 3 shows the power requirements of each component in the electrical system. With the removal of the A-Plus computer from previous years, the maximum power consumption is reduced by 124W, but is still high owing to the two motors. The average consumption, however, is estimated to be 240W. Average consumption is difficult to quantify precisely because it is affected mostly by how much power the motors draw.

Table 1: Max power consumption

Component	Voltage (V)	Current (A)	Power (W)
Motors/Encoders (2x)	24	20.8	500
Laser Range Finder	24	1.8	43.2
Laser Range Finder	24	1.8	43.2
DGPS	12	1.25	15
E-Stop Receiver	12	0.75	9
Ambient Light Sensor	3.3	0.02	0.0033
Ultrasonic Sensor (2x)	5V	0.03	0.15
GEDC-6 Compass	3.3V	0.0097	0.032
Total Maximum Consumption			610.6

4.4 Improvements

Two years ago, Reagle's connectors exited the electronics box from the right hand side as shown in Fig. 8. The connectors' position caused problems when the vehicle collided with obstacles on the right side. The connectors broke and were not easy to maintain. In addition, Reagle experienced electrical problems that resulted from faulty wiring and tracing. Last year, Reagle experienced faulty wiring from stresses on the connectors that came out the front of the pelican case and were exposed to the environment. For ALVIN, the entire vehicle was rewired and reorganized. The connectors were replaced with new Molex automotive connectors (Fig. 7) and moved to within the frame. Passageways allow the wires to flow between shelf levels. The connectors also have convenient, easily removable pins and quick release locks. The previous vehicle exposed the laptop to the elements, while ALVIN protects the laptop on a shelf within the tower frame and allows head-level access.


Figure 8: Old connector system


Figure 7 Last year's connector system

4.5 Emergency Stop System and Safety Strobe Light

ALVIN incorporates the SafeStop emergency stop system from TORC Technologies shown in Fig. 11. The SafeStop transmitter uses spread spectrum frequency hopping for decreased interference and reliable transmission of up to 6 miles line-of-sight. The transmitter's battery lasts

Figure 9: E-stop transmitter and receiver

30 hours on a single charge. As implemented, the SafeStop system provides a pause mode and a "hard" emergency stop mode. The pause mode rapidly brings the vehicle to a controlled stop without cutting power. The "hard" emergency stop opens a relay, disengaging all electrical power. A separate radio controlled transmitter is used to drive the vehicle in non-autonomous mode. Mounted strobe lights indicate to bystanders when ALVIN is under autonomous control.

4.6 Sensor System and Integration

ALVIN uses eight commercial-off-the-shelf (COTS) sensors as shown in Fig. 12 below. The central point of integration is a DELL Latitude Laptop with a Core i5 2.50 Ghz processor, 4 GB RAM, and 256 GB solid state hard drive. The LabVIEW programming environment installed on the laptop is the central point of software integration. LabVIEW is a critical tool used to receive and organize data from the sensors and run all software algorithms.

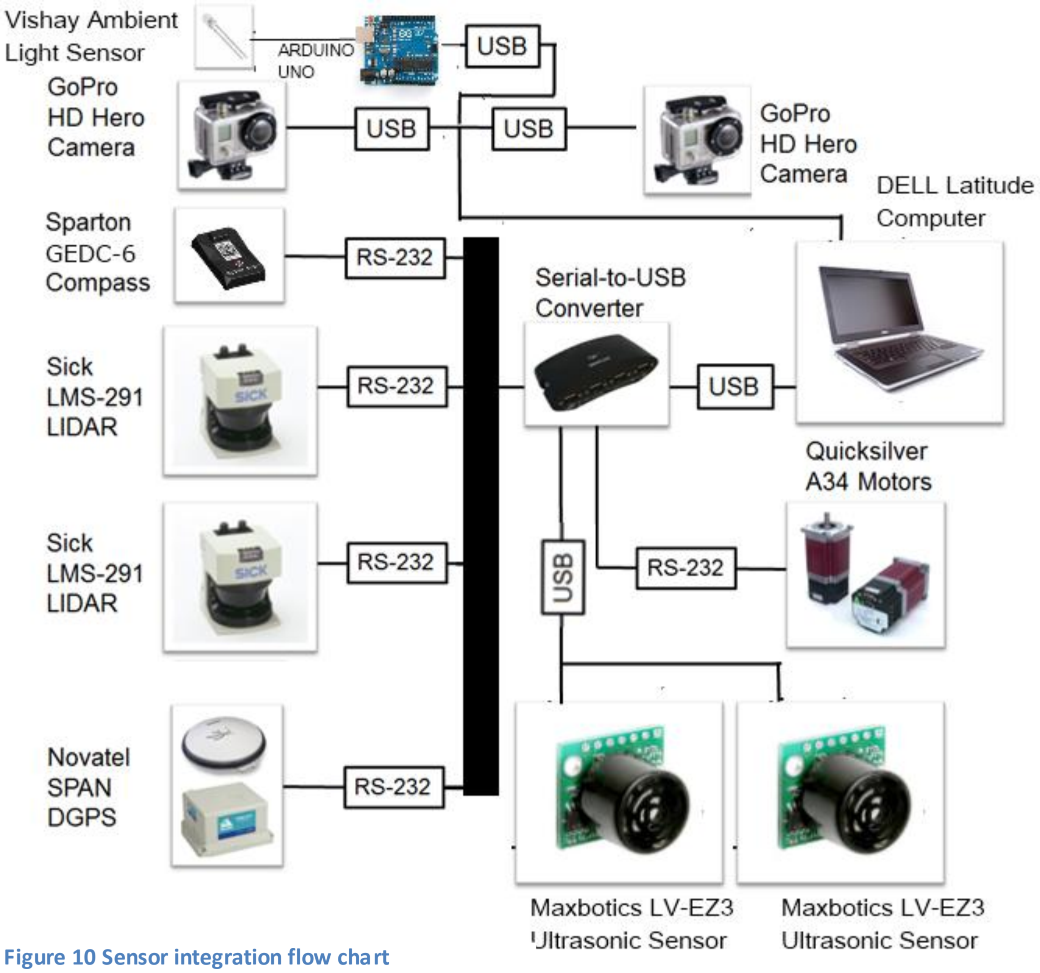


Figure 10 Sensor integration flow chart

LRF — Sick's LMS 291 laser range finder scans for obstacles in a 180° planar sweep in 1° increments at 20 Hz. The maximum sensing rage is 80 m, but ALVIN limits detection to obstacles within 15 m. Resolution is 1 cm, and accuracy is ±3.5cm. 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 laptop via RS-232 and a serial-to-USB converter.

DGPS — Novatel's SPAN Differential GPS, used in tandem with a Novatel GPS 702 GGL antenna, combines global positioning satellites with the OmniSTAR HP correctional service. Uncorrected accuracy is usually 1-2m CEP. Correction with OmniSTAR HP decreases the uncertainty to sub-decimeter range. The SPAN system integrates an IMU with a Kalman filter, so continuous inertial solutions can be output at up to 100 Hz. ALVIN accesses the fused GPS-inertial solution at 20 Hz. GPS data is transmitted to the laptop via RS-232 and a serial-to-USB converter.

Digital Compass — The Sparton GEDC-6 digital compass for navigation is a six-axis accelerometer/magnetometer that measures heading, pitch, and roll information with 1° RMS accuracy at 0.1° resolution. ALVIN accesses the orientation data at 20 Hz via RS-232 and a serial-to-USB converter.

Digital Camera — The GoPro HD Hero is an outdoor sport, consumer grade 5 megapixel digital camera with a very wide 170° field of view lens. 720x480 standard definition video is streamed to the computer with a digitizer and captured at 20Hz. The GoPro camera runs off its own battery power with a typical use time of one hour continuous streaming.

Ultrasonic Sensor- The MaxBotics LV-EZ3 ultrasonic sensor is a low-cost, low-power, and high performance range finder with a detection range of 0 to 254 inches. The ultrasonic sensor provides range information for a distance of 6-254 inches (.45 meters) with 1-inch resolution. The ultrasonic sensors sends range data at 20Hz to ALVIN's central laptop hub.

5 SOFTWARE SYSTEM

5.1 Structure

ALVIN's software system was developed using National Instruments LabVIEW. LabVIEW was chosen because it provides an intuitive Graphical User Interface (GUI) which allows the user to easily monitor, modify, and debug software. The GUI is helpful in verifying that all of ALVIN's sensors and components are fully operational before the autonomous program is run.

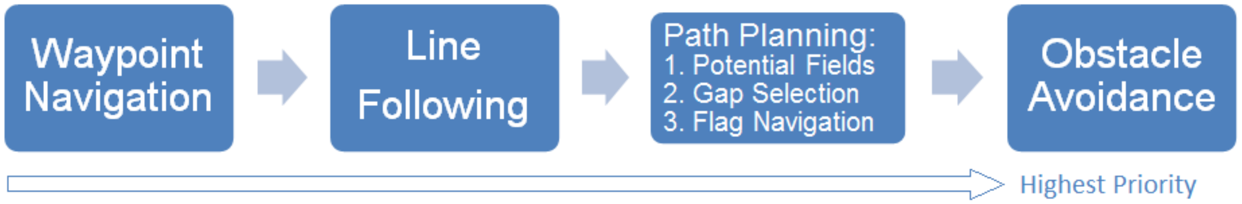


Figure 11 Software Architecture

The code is broken into four major sequential steps, with each later process able to make use of and subsume the previous decision. The steps are waypoint navigation, line following, path planning, and obstacle avoidance (Fig. 11). The path planning step has three possible states depending on which scenario ALVIN is currently facing. For example, the flag navigation algorithm is active only after the second to last waypoint is hit.

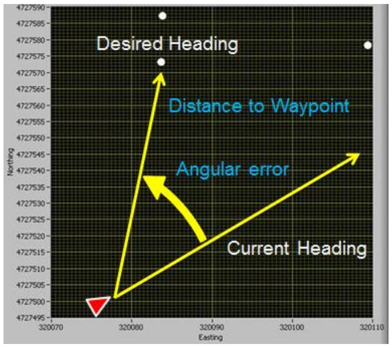


Figure 12 Waypoint Navigation

5.2 Waypoint Navigation

The first part of ALVIN's software structure consists of Waypoint Navigation. The GPS and compass provide ALVIN's current position and heading, respectively. With this information the angular error and the distance to the target waypoint can be calculated. As depicted in Fig. 12, ALVIN will simply drive straight to the waypoint without the presence of any obstacles.

5.3 Line Following

Once the direction to the waypoint is determined, the next section of code implements line following. The line following flow diagram, shown in Fig. 11, illustrates the primary steps in the line extraction algorithm. First, box covers are placed at the top and bottom of the image to block out the horizon and vehicle, respectively, since both can have very bright pixels that can saturate the image and are not lines. Next, the image is down sampled from 720 x 480 to 160 x 120 to blur some noise and reduce processing time. A 2:1 plane threshold of blue and green filters is performed to obtain a grayscale image. The image is also split into a left and right half, since there are potentially two dominant lines in the image.

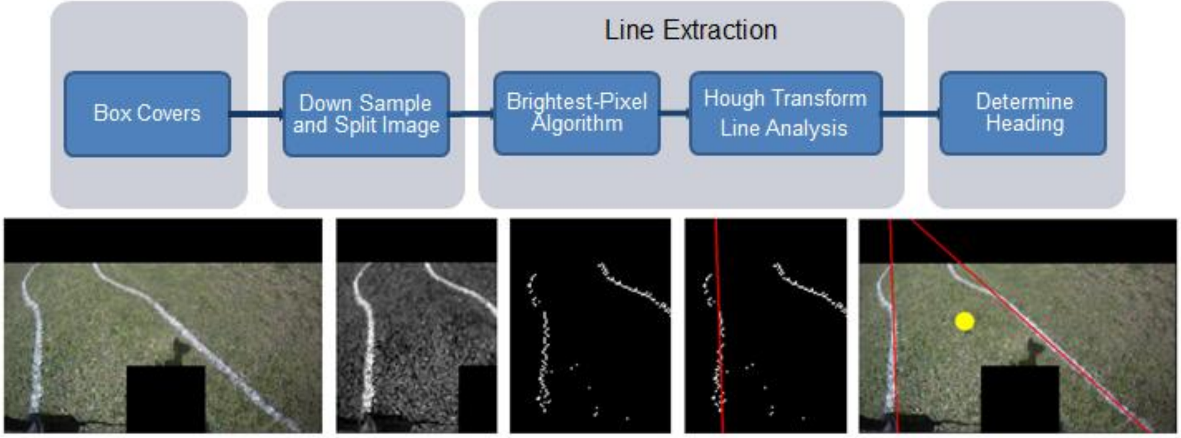


Figure 13 Line detection algorithm

A brightest pixel algorithm isolates the white pixels by scanning both horizontal and vertical lines for the pixel(s) of highest value. Then, a Hough transform uses a voting system to determine the slope and distance to the dominant line traced by the pixels of each half-image. It is possible that no line is detected in the image if no candidate receives a minimum number of "votes" in order to be considered a line. If lines do exist, they are categorized as horizontal or vertical, and compared with each other as parallel or intersecting.

The last step is to recombine the half-images and use a decision tree to select the heading given the possible combinations of lines in half-images. For example, if both images detect a line, the heading should be between them. If only one image contains a line, then the heading should be a few feet left or right of this line as appropriate to stay within the course.

5.4 Wall Following

The wall following algorithm implements range reaction. ALVIN will react to an object if it is between 1.2 and 1.6 m. For example, if ALVIN follows a wall on the left and if any obstacle to the left is within 1.2m (~4 ft) then the robot will turn right to move away from it. If the obstacles are within 1.2 and 1.6m, then the robot will drive straight ahead. If the obstacles are farther than 1.6m, then the robot will turn left, towards the wall.

The second wall following algorithm operates at the waypoints closest to the wall by identifying the obstacle line and using the gap selection algorithm to detect which of the three gates is open by process of elimination.

5.5 Flag Detection

For the advanced course in the competition this year, blue and red flags are arranged in a complex row arrangement. The flag detection algorithm uses three simple steps (Fig. 14). First, it retains the same box covers as the line detection algorithm to block out parts of the image that are near the horizon or vehicle. Then it performs a mixed-plane threshold based on hue (color), RGB ratios, and HSL values to determine pixels that qualify as either blue or red. Finally, a particle filter is used to eliminate blobs that are too small or too large to possibly be flags. The results are overlain on the GUI so that the user can immediately see what has been detected as a flag and make adjustments as needed. This year, the field of view for detecting the flags is minimized to reduce the probability of detecting objects off the field.

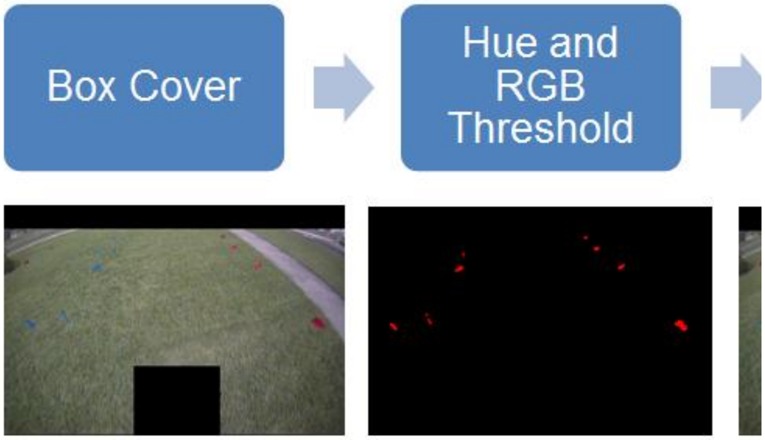
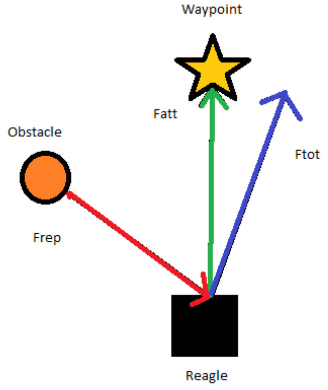


Figure 14: Flag detection

5.6 Potential Fields Path Planning



For obstacles that are more than 2 meters away, ALVIN has a path planning algorithm based on the concept of potential fields. The potential field method is essentially an equation of attractive and repulsive forces:

$$F_{att} = k_{att} * d_{wypt}$$

$$F_{rep} = \frac{k_{rep}}{d_{obs}^2}$$

$$F_{tot} = F_{att} + F_{rep}$$

Figure 15: Potential fields path planning

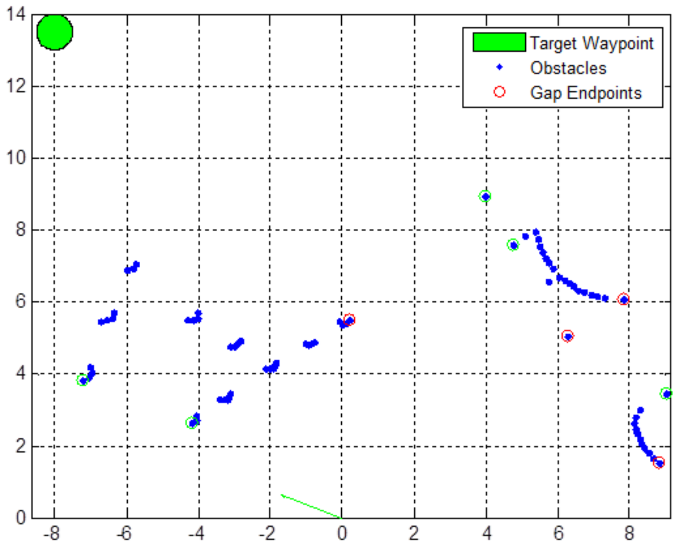
The attractive force pulls the vehicle towards the weighted waypoint, while the repulsive forces push the vehicle away from obstacles (Fig. 15). The net force determines the vehicle's desired direction. These virtual forces are functions of the distance to the waypoint and distance to the obstacle.

Local minimum pose a major problem for using potential field algorithms. This phenomenon occurs when the vehicle enters symmetrical trap situations such as dead ends. At a local minimum, the repulsive forces act so strongly around the vehicle that they are essentially equal to the attractive force. This causes the vehicle to come to stop and be unable to reach the waypoint. In order to avoid local minima, the gains for the attractive and repulsive forces have been tuned such that it is less likely to occur, and a wall following algorithm has been implemented as explained in the dead end section.

5.7 Gap Selection Path Planning

ALVIN makes use of a long range optimal heading algorithm for gap identification and vehicle maneuvering. Although ALVIN's vision system sees a 180° FOV of objects at up to 80 meters away, the obstacle avoidance algorithm only makes use of data points within a set 2 meter distance threshold of the vehicle. This results in somewhat clumsy paths that can be characterized as simply straight lines towards the next waypoint until an object is within 2 meters, at which point the vehicle will make a sudden left or right turn.

The path planning algorithm eliminates this sub-optimal behavior by making use of data within a range of 15 meters. The algorithm analyzes the obstacle data and segments objects so that any gap greater than the vehicle's tolerance width for passing through, about 1.5 meters, is marked as either a left-handed or right-handed opening. In Fig. 16, the small green circles represent left-handed openings and the red circles mark the right-sided ones. The green arrow shows the heading that the algorithm has determined leads to the optimal opening. With this algorithm, ALVIN can drive straight to the optimal opening



instead of simply driving straight until it is in close proximity to an obstacle.

Given the limitations of the LRF, namely that it cannot see through objects, this technique provides improved behavior going towards unknown parts of the course, because even a mapping solution cannot map unknown parts of the course given the same sensors.

Figure 16 Gap selection path planning

5.8 Obstacle Avoidance

5.8.1 LRF

ALVIN's obstacle avoidance algorithm operates when the vehicle is within 2 meters of an obstacle. The LRF sensor provides angular position and distance information that enable the obstacle avoidance algorithm. The LRF's 180° field of view is broken into five zones: center, middle left/right and far left/right. Fig. 17 below shows the vehicle with the zones defined. The segmentation of these zones can be modified by the user but are currently set at: 0° (due right), 30°, 65°, 115°, 150°, and 180° (due left). A zone is considered occupied when an obstacle is within 2 meters. An occupied zone indicates to ALVIN the instruction to turn in the opposite direction.

While each zone is labeled as occupied or unoccupied, the algorithm continuously uses a decision tree to decide the path to avoid obstacles. The main check on the decision tree is to check if the center cone is occupied. If that cone is occupied, it goes on to check if the previous command was left or right. Next, the middle left or right, respectively, is checked to see if it is occupied. This decision tree continues on for all possible combinations of cones and objects.

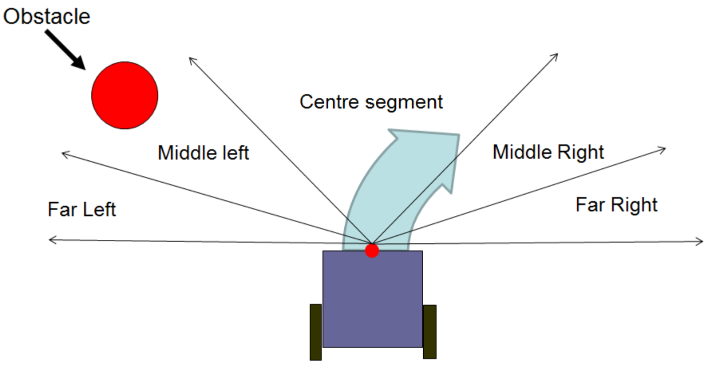


Figure 17 Obstacle avoidance zones

5.8.2 Ultrasonic Sensors

An ultrasonic sensor is positioned on each side of the robot to cover the blind spots of the LRFs. Although the two LRFs each have a nominal 180 degree field of view, the configuration of the robot creates some blind spots near the wheels. The ultrasonic sensors ensure detection reliability for these areas.

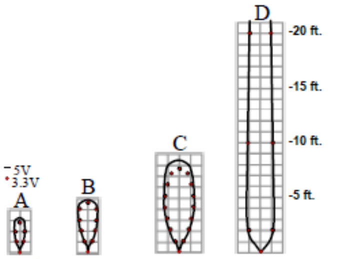


Figure 18 Beam Detection Pattern

5.8.3 Rear Detection

New this year is an algorithm enabling ALVIN to detect obstacles behind the robot so the robot can back up with successful obstacle avoidance. This function primarily turns on in the code when the vehicle enters the field of waypoints and when a dead end is detected. A second LRF and GoPro camera are added to ALVIN's sensor and software systems to implement this Dual-Vision strategy that enables forward and backward directional driving.

5.9 Complex Obstacles

5.9.1 Switchbacks

A switchback occurs when the field requires the vehicle to successfully navigate through a zigzag like obstacle course. ALVIN handles switchbacks using the waypoint navigation and the five zone obstacle avoidance. The waypoint navigation knows the waypoint's location and uses the angular error to calculate the desired heading. ALVIN effectively avoids obstacles by using the five zone obstacle avoidance; the vehicle will recognize the minimum gap of five feet and be able to make it through without hitting any of the obstacles. Fig. 17 depicts ALVIN's desired path for a switchback situation.

5.9.2 Dead Ends

A dead end is a complex situation requires ALVIN to use more than just the waypoint navigation and the five zone obstacle avoidance. With only these, ALVIN would continuously circle in the dead end. To correct this, a dead end algorithm using new rear LRF detection has been implemented. The dead end algorithm is broken down into three sections. The sections are: recognizing the dead end, the action to take in order to get out of the dead end, and turning off the algorithm.

ALVIN recognizes the dead end by constantly checking to see if there is an obstacle in the three main zones for more than fifty percent of the time. This, in conjunction with any turn greater than 120°, will activate the dead end algorithm. The plan for getting out of the dead end is to use rear vision detection and backward driving. ALVIN will identify the obstacles and use the gap planning algorithm to determine the desired direction and optimal path to navigate out of the dead end. The code will turn off when ALVIN moves a certain distance away from the dead end obstacles. Fig. 21 shows how ALVIN would get out of a dead end situation.

5.10 Matlab Simulator and Data Replayer

The software also has a data logging system which outputs all sensor and algorithm information into a text file that can be imported into Matlab and replayed. The data logging system helps immensely with the test and refine process by identifying problems that cannot be immediately noticed by vehicle performance inspection during a test.

The output of the program is shown in Fig. 22. The black rectangle represents the vehicle's

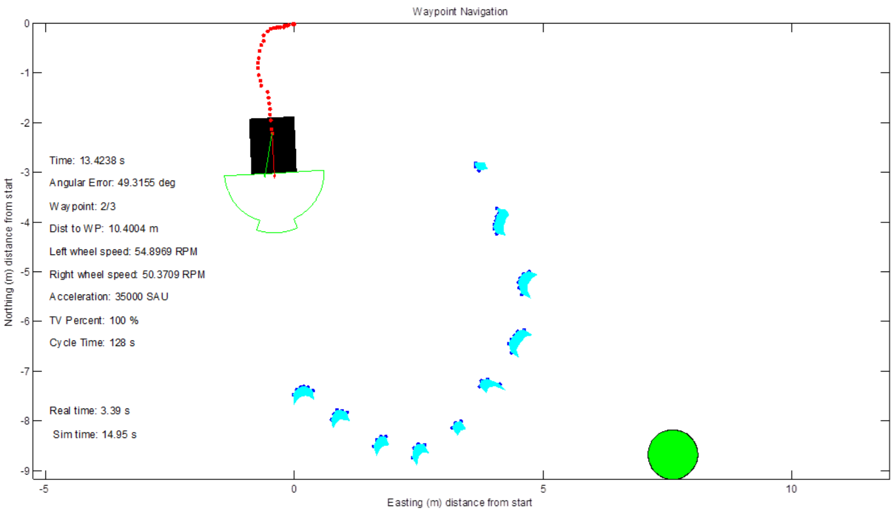


Figure 19 Matlab Simulator

footprint, while the blue represents obstacles, and the green circle is the target waypoint. The green semi-circle extending from the vehicle is the obstacle avoidance range, and any obstacles within that range will be reacted to. The red dots show the vehicle's GPS trail. On the left hand side are numerical values that can be customized to whatever the user wishes to see, including elapsed time, wheel speeds, latency, etc.

6 COMMUNICATIONS

6.1 JAUS Protocol

The Joint Architecture for Unmanned Systems (JAUS) is an SAE standardized communication protocol that has been implemented on ALVIN. 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. ALVIN 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. ALVIN 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.

6.2 Latency (Reaction Times)

ALVIN's software code is able to run at about 9 Hz on an Intel i5 2.30 Ghz dual core processor and 4 GB RAM on Windows 7 (x64). The vision algorithms take about two-thirds of this processing time. Similar to Reagle, ALVIN can access sensor data at 20 Hz or faster, so the limiting factor is the speed of ALVIN's main algorithm process.

Table 2: Latency

Latency		
Process		Time (ms)
Grab Camera Image		21
Vision	Line detection	40
	Flag detection	25
Path Planning		20
Obstacle Avoidance		9
Total		115

7 CONCLUSION

ALVIN is a successor to the reliable Reagle platform legacy, while implementing a safe, maintainable, accessible, protected integrated systems design that meets all of the requirements and challenges of the 2013 Intelligent Ground Vehicle Competition. Through extensive design, testing, and analysis, the vehicle includes new innovative features such as the ambient light sensor, the dual vision, rear driving, and tool shelf, and optimizes its previous hardware and software features for increased reliability in this year's competition as well as potential expansion in future competitions.

8 REFERENCES

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