

Robo-Goat: An Autonomous Mobile Robot for AUVSI's IGVC



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Abstract

Robo-Goat is a Naval Academy legacy project that was started in 2009 for the purpose of competing at AUSVI's IGVC (Intelligent Ground Vehicle Competition). Last year a stable platform was created and this year the goal was to improve upon the platform without starting from scratch. This version of Robo-Goat will compete at the 2010 IGVC. A final design configuration was driven by the rules and regulations of the IGVC. One way that this project is constrained, that is separate from the IGVC, is that the previous platform will remain the starting point. Much time and effort was put in the platform and it works well as a starting point. It would take too much time and effort (that will be devoted to furthering the capabilities of the platform) to start from the beginning again.

To aid our design, research was done on some other platforms that competed and did well at previous competitions. This research yielded some insights that were considered in our design process.

The main purpose of our entire design process has been to find weak areas of the previous design where improvements can be added by this year's team. Throughout this process it was important to make sure that none of the new changes negatively affected the current capabilities. The weak areas are not due to the failure of the previous team, but due to the nature of their project. Last year's goal was to get a working platform; this year's team has the luxury of having a working platform from the beginning so higher level work can be done. The changes have been kept open to both hardware and software.

In terms of hardware (as was mentioned previously), it has been determined that it would not be beneficial to start from scratch. What is investigated, in terms of hardware, is the frame and its material, better organizing the structure, and altering the center of gravity. The body material was investigated for the purposes of weight and center of gravity and ultimately Plexiglas with an aluminum frame was used. The internal organization, especially the wiring, has been drastically improved by being much neater, with accompanying circuit diagrams, and a hardwired board for more secure connections. Previously, when Robo-Goat went up an incline, it would rest back on its wheelie bars and the directional control becomes problematic; by moving the center of gravity forward the problem has been solved.

There is much room for improvement and refinement for the software as well. Software will be improved to enhance lane following and obstacle avoidance as well as coordination between lane following, obstacle avoidance, and GPS navigation. Lane following has been slightly problematic because of varying outdoor lighting conditions. New hardware, both a new camera and a new laser with more capabilities, additionally aid in the improvement of these aspects. Specifically, by using a laser to get a scan of greater than 180 degrees, obstacles are still seen in the scan after the front of Robo-Goat breaks the plane of the obstacle. The issue of clipping obstacles as the vehicle passes by has been solved.

By modifying and adding to the software and the hardware of Robo-Goat, not only will it be more adapted to and prepared for the 2010 IGVC, but it will overall be a more versatile platform.

Project Overview

Robo-Goat is a legacy project that was started last year in the Weapons and Systems Engineering Department. The purpose of this project was to construct an autonomous ground vehicle that would be able to compete in AUVSI's (Association for Unmanned Vehicle Systems International's) Intelligent Ground Vehicle Competition (IGVC). Last year the team was able to put together a functioning robot that went to the competition and did well, earning the rookie of the year award. With this in mind, the problem statement for this year is:

To improve upon the 2009 design for the IGVC by investigating the vehicle concept, software, and hardware, in order to be competitive in the 2010 IGVC Navigation, Design, and Autonomous Challenges.

The objectives derived from our problem statement are:

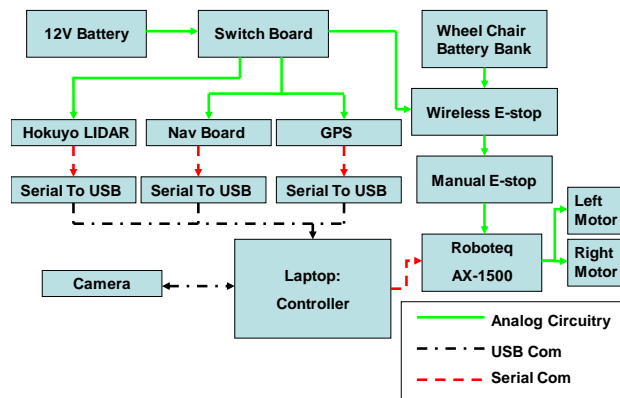
- Easy to Modify
- Quick to Initialize
- Easy to Remotely Monitor
- Weather Proof
- Emergency Stop (loose wire problematic last year)
- Avoid Obstacles (prevent side swipping)
- Follow Lanes (more robust method which handles cases such as heading straight at a lane marking)
- Stability on inclines
- Repeatability

Design Narrative

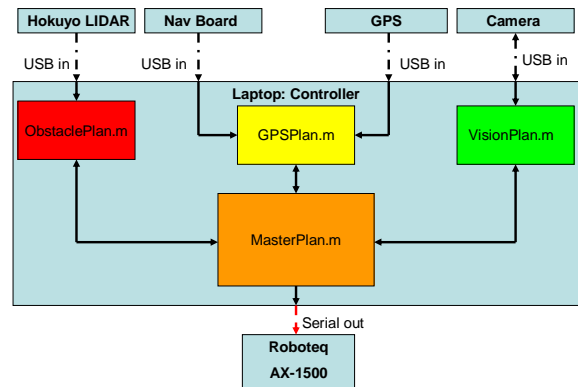
This design is broken down into three major sections:

1. Body design: all structural components and construction (not specific to the other major sections), along with the electrical system and wiring inside the vehicle.
2. Vision system: this includes the camera, camera mounting systems, all software involved with the camera, and all software that uses information from the camera
3. Laser system: This includes the laser, laser mounting all software involved with the laser, and all software that uses information from the laser

In terms of hardware components onboard the vehicle, all of the sensors feed into the laptop computer through USB ports and the laptop will output commands to the AX-1500 Roboteq board wheelchair motors. The software used is quite simple to operate. MATLAB is the primary programming language and shortcuts have been created on the laptop to accomplish initializations and running the vehicle in single mouse clicks. The basic architecture of the program is shown below. All of the sensor information that comes into the laptop will feed into one of the lower level programs, which will decide what to do with the information. The *MasterPlan.m* program contains parameters that may be adjusted before running the vehicle. The basic architecture of *MasterPlan.m* is the parameters and some initializations followed by a continuous loop that calls the lower level programs, takes the information and decides what commands to send to the motor.



Hardware functional block diagram



Software functional block diagram

Body Design

The chassis that Robo-Goat is built upon is that of a *Drive Sunfire Plus* rear wheel drive wheelchair. This hundred and thirty-two pound wheelchair has a differential drive system with a zero point turning capability. Controlling the two rear wheels are a pair of two DC motors powered by two 12V batteries with an onboard controller. The legacy Robo-Goat's wooden chassis, with all the electrical components attached, weighed a little over a hundred pounds. It was attached to the wheel chair at two points by two steel rods welded to the front of the wheel chair frame while also resting on the seat post.

The legacy Robo-Goat design had many potential improvements that the team planned to make. First, it was a very heavy unit weighing in at a total of two hundred and thirty-two and a half pounds making it difficult to transport. Second, the unit was not protected from the elements, which proved to be troublesome due to the weather conditions at the 2009 IGVC competition. Third, the center of gravity of the chassis was located toward the rear of the vehicle causing it to tip on inclines of approximately 10° or more. Fourth, the wooden sides and poorly hinged access door made it difficult to observe and access if any problems were to occur. Lastly, the organization of the electrical components and their wiring was inadequate and difficult to analyze. Also, the components were powered by three twelve volt batteries. The goals for the design of the body were to fix these deficiencies. In order to do so, four different designs were developed to choose from. The first consisted of keeping the current wooden frame with an exposed deck, making minimal changes. The second also consisted of keeping the current wooden frame but adding a cover on the top tier in order to better protect it from the elements. The third supplied a two-tiered aluminum platform with windows that would provide more of a viewing capability. Lastly, there was the option to make the body completely out of Lexan, for maximum viewing ability and durability, with a covered top tier. This year's design was a combination of ideas from options three and four.

Two inch by two inch hollow aluminum square tubing was used to create the frame and quarter inch plexiglass was added to the sides for observation. A plexiglass panel to cover the top tier container was also created to protect the laptop and other connections from the elements. Additionally, the top tier container was oriented in

such a way where the laptop would face toward the rear, instead of to the side as the original Robo-Goat was, providing easy observation while the unit was in motion.

Both containers are sealed with hinged latched doors, lined with weather stripping, for easy access without compromising the unit's water tight integrity. Wood was used for the decks due to its easy mounting (screws can be used and components can easily be moved around or added if desired) and no conductivity problems (with a conductive deck, such as metal, it would be easy to create a short circuit by accident). Redesigning the body shaved off nearly thirty-five percent of the legacy Robo-Goat's weight, taking it down to sixty-seven and a half pounds. The center of gravity for the chassis was also moved two inches lower and six inches more forward than the legacy Robo-Goat. This provided more stability on inclines and prevented tipping on inclines greater than ten degrees. In order to attach the chassis to the wheelchair, a different and more creative method was used. Three bike seat shocks and created adaptors were used to separately attach the chassis and wheelchair.

Using these shocks not only provided more stability on different terrain, but also gave us an option to separate the wheelchair from the chassis of the Robo-Goat. Instead of moving a two hundred pound unit, this option makes separates the unit into a hundred and thirty-two and sixty-seven pound pieces making transportation simpler in terms of labor and also bestows easier access to the components of the wheelchair.

All of the interior components are protected from the elements by the design of the vehicle, but it is also necessary to water proof the external components: the camera and the global positioning system. To accomplish this, brackets were added to the rear facing side of the mast so that an umbrella can be easily attached and detached as it becomes necessary to do so.

Additionally, the wiring was reconfigured and two of the previous three twelve volt batteries providing power to the compass, GPS, and laser were subtracted. To control the powering of each system, a switch board was designed, that provided the opportunity to enable and disable the emergency stop, laser, and the navigation board.

The wireless emergency stop circuitry was also upgrade to a more permanent board for the voltage regulator and wireless Futaba system, taking out unnecessary components. The addition of screw terminals allows for a more stable, secure, and flexible system.

Laser System

a. Final Design

The final laser design implemented was actually not one of the proposed configurations from last semester: using one Hokuyo URG-04LX Laser. The single, forward-facing laser with a 240 degree scan is mounted upside-down on the undercarriage of the vehicle body, as close to the vehicle's center of gravity without the undercarriage interfering with the scan. For each scan, 0 is straight ahead, -120 degrees is to the left and +120 is to the right, that is, -120 to +120 going clockwise from a top-down perspective. Each scan return is a +/- 0.3515625 step; for processing every third step was analyzed for a resolution of just greater than 1 degree.

By mounting the laser on the undercarriage, the shortest obstacles we anticipate, a 5 gallon bucket, will be in view of the laser. Also, the laser is closer to the pivot point of the vehicle for more accurate information regarding heading corrections and necessary angular velocities to avoid obstacles. Though the laser is very light, 5.0 oz (141

gm), and insignificant relative to the mass of the rest of the vehicle, it is still mounted near the vehicle's center of gravity and does not change the desired effect from the new body design.

Three functions govern the use of the laser system: one to initialize the laser, *GoatNavLabInit.m*, one to take a scan, *GoatRangeNavLab.m*, and one to analyze the scan for obstacle and gaps, *AnalyzeScan.m*. (The function to analyze a scan condensed three functions from the 2009 team into one.) Lastly, a final script was created to drive the vehicle solely off the laser, *DriveWLLaser.m*.

The initialization and scan code are very simple. For initialization, a serial port object is established in communication port 24 and opens the connection at a 19200 baud rate. Additionally, the designation of "theta" is established in radians, as well as the desired returns from the laser (remember: only analyzing every third step). The scan code is essentially the same as the code developed by the 2009 team, assigning returned ranges (in cm) to each theta and designating a max returned of 1000.

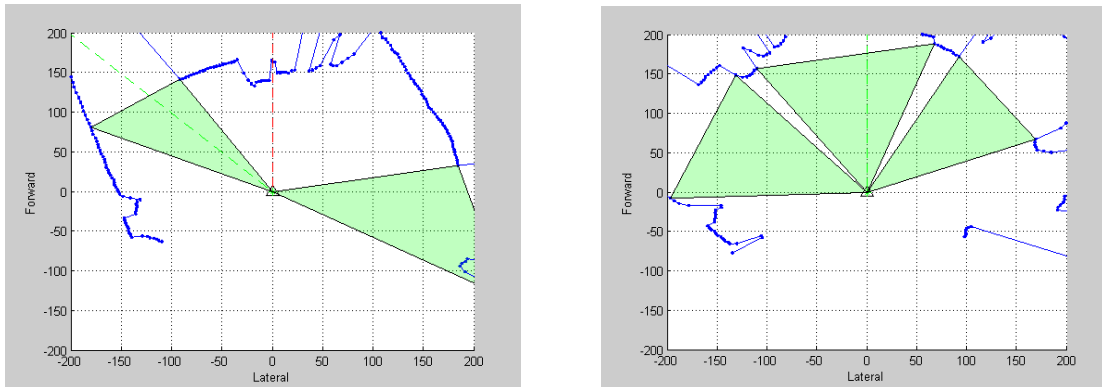
AnalyzeScan.m has five inputs and three outputs. Its inputs are desired heading, which comes from the camera vision system or can be designated by user input if driving the vehicle solely off the laser, range and theta both from the initialization and scan code, and two variables that can be adjusted for avoidance performance, thresh and buffer. Thresh is the maximum distance at which an obstacle is still considered an obstacle. If the object is a greater distance than the threshold, it will not be recognized as an obstacle until the vehicle is closer. Buffer is a width added on to each side of the vehicle, used later to determine if a gap is feasibly large enough for the vehicle to pass through. The three outputs are the best heading to steer, and the maximum percentage of forward and angular velocity the vehicle drive while executing the course adjustment.

The analysis to determine the best heading is as follows. First, gaps are recognized as wherever a return is greater than the threshold and are then labeled to identify how many gaps were present in the scan. If no gaps are detected, the vehicle will proceed at the heading provided by the camera at a 50 percent forward velocity. For the gaps that are detected, the left and right side of each gap is separately labeled as indices. Each gap can be thought of as a cone with the vehicle as its vertex. To find the width through the narrowest part of the gap, the heading through the center of that gap is calculated and the closest obstacle edge is determined.

Any gaps that do not allow the passage of the buffered vehicle are eliminated from further analysis; the remaining gaps are considered "feasible gaps". If the desired heading is in a feasible gap, then the desired heading is considered the best heading. If there is an obstacle at the desired heading, the closest edges of neighboring gaps are found. These edges are then "dilated" because if the vehicle were to drive straight to the heading of the obstacle edge it would likely clip the obstacle. Once the edges are appropriately dilated, they are compared to the desired heading and whichever is closer is designated as the best heading.

Velocity percentages are determined by the best heading and the distance to the closest obstacle. Provided there is a gap to go through, the maximum percent of forward velocity permitted is $1 - 10 / (\text{distance to closest obstacle})$. If there aren't any gaps detected or all are too small, the forward velocity is reduced 50 percent. Problems were mostly encountered with determining angular velocity; at this juncture, angular velocity is determined by $(\text{best heading}) / \text{constant-bias}$. If there aren't any gaps or all gaps appear too small, the angular velocity defaults to a maximum percentage of 0.05, in order to acquire a new perspective and hopefully recognize feasible gaps.

The figure showing feasible gaps and headings is displayed every scan. The x and y axes are in centimeters and the vehicle is represented by the triangle in the middle. The light green shaded areas are feasible gaps. The desired heading plots in a red dashed line while the best heading is a green dashed line. If no red line is visible, the desired heading is the best heading (that is, it's in a feasible gap). This display causes a significant amount of lag in the program which impedes the obstacle avoidance capability from becoming as effective as possible. From the “profile” command it is evident that the plotting takes over a second for each iteration, more than half of the time passed for each iteration. Suppressing the plot decreasing run time, however it is near-impossible to follow what the vehicle is processing and executing without the graphical feedback. Improving this aspect is certainly desirable.



Left: An example of figure when desired heading (red) is not feasible due to obstacle present so best heading (green) is recommended as next best alternative is shown.

Right: An example of figure when desired heading is feasible so best heading (green) is same as desired heading.

b. Design Process

By keeping a single forward-facing laser with a wider scan we maintained the “4” in Easy to Modify, achieved a modified “3” in Avoid Obstacles, and achieved repeatability no better or worse than either a single forward-facing laser or the additional side-mounted lasers. This final configuration eliminated the need to initialize and integrate multiple lasers while maintaining recognition of obstacles after the plane of the front of the vehicle passes them. (Clipping obstacles and turning into them after they passed the plane was a significant problem for the 2009 team.) Furthermore, it was deemed unnecessary to scan and detect obstacles behind the vehicle since it will never reverse. Also, we only needed to purchase one new laser instead of two, arguably three if the SICK laser was to be replaced with a much smaller laser such as the one we purchased. The final benefit to the laser we used in the final configuration is that it is a laser the group is familiar with since it is used in other Systems Labs. An unexpected benefit of this commonality is that when the purchased later inexplicably stopped working, the team was able to borrow a laser from the lab and did not have to independently acquire a new laser or change any software.

The process of developing the software, specifically *AnalyzeScan.m* took much longer and was a process that was not accounted for during the design phase in the fall. The concept of finding the “cone” for each gap was used last year but an arbitrary limiter was applied, determining that a cone of less than 77 degrees was unfeasible. Using the trigonometry involved evaluates each cone on a case-by-case basis for feasibility. In order to find the closest obstacle, the code initially used an ‘if statement’ which made maintaining the proper coupling of distances

and angles difficult and returned a vector with null elements that later had to be ignored. This process was simplified greatly by some *min* and *max* comparisons.

Once the project progressed to the stage of feasibility, each gap used to be classified by the heading through the center of its gap. The problem with this is that later in the logic to determine which gap was closest to desired, even if the desired heading would be within a feasible gap the best heading would default to the center of the gap. This is no longer the case. If the desired heading is anywhere in a feasible gap, the vehicle will travel along that heading. Also improved is the way edges of obstacles are dilated to better ensure unimpeded passage of the vehicle. An initial conceptual error led to poor results. The width of the vehicle must be perpendicular to the path the vehicle will travel, which is the adjusted heading, so the dilation angle correlates to the sin function of buffer width and distance to the obstacle. Before, the width of the vehicle was considered to be perpendicular to the closest possible path, which would be the path leading to the closest point in obstacle. Therefore, the dilation angle correlated to the tan function of buffer width and distance to the obstacle.

Another major improvement was the final determination of best heading. The 2009 attempted to construct a weighted matrix (like Q for Control Systems) but weighted the heading closest to straight so heavily (100 times) that the heading closest to straight always prevailed. Now, instead of a comparison to straight, the heading options are compared to the desired heading, which although defined as 0 for test purposes could just as easily be defined as anything with the scan of -120 to $+120$ degrees.

c. Component Details

Laser specifications are (from Acroname Robotics):

Specifications	
Power source	5V +/-5%
Current consumption	0.5A (rush current 0.8A)
Detection range	0.02 to approximately 4m
Laser wavelength	785nm, Class 1
Scan angle	240°
Scan time	100msec/scan (10.0Hz)
Resolution	1mm
Angular Resolution	0.36°
Interface	USB 2.0, RS232
Weight	5.0 oz (141 gm)

<http://www.acroname.com/robotics/parts/R283-HOKUYO-LASER1.html> [1]

Communication protocol is simple and mostly included in the *DriveWLASer.m* script. To drive the vehicle off the laser, switch the “Laser” and “E-Stop” toggles on the top of the vehicle to “on”. Turn the Futaba on and

ensure Channel 5 toggle is down. Ensure the gears for the power wheelchair are engaged, that is, the black handles above the rear wheels are oriented fore-and-aft. The last component to engage the wheels is to depress the small white button under the manual E-Stop on the rear of the vehicle. (This step can be done after the software initialization and the first few scans are returned if you'd like to verify proper function of the analyzing code.) From here, *DriveWLASer.m* can be used, which initializes the laser and Roboteq board, then continuously takes scans and drives the vehicle off the best heading.

d. Equipment List

To reproduce this design, the following equipment is needed:

- Hokuyo URG-04LX Laser
- Power Source < 5V, <0.8A
- 5V Voltage Regulator
- USB Cable (in addition to cable provided with laser) to connect to laptop
- Serial-to-USB Converter

Vision System

The vision system has been heavily upgraded since the 2008-2009 academic year version of the vehicle; the camera has been replaced, the camera is mounted more securely, the camera's vision is integrated with the laser coordinate frame, and the lane following capability has been improved.

a. Hardware

The camera for last years design was a Creative Live Notebook Ultra webcam. This camera worked well, it had various modes of resolution (maximum of 640 x 480 but also 320 x 240), it came with a software console where various parameters (such as exposure and auto white balance) could be changed, and it connected to the laptop through a USB port. One issue with the camera was its large amount of distortion toward the edge of the image. This year the webcam was exchange with a DFK 21BU04.H from The Imaging Source. This is an industrial color CCD camera with a set resolution of 640 x 480. This camera also connects to the laptop via USB. The downsides to using this camera are that the resolution is fixed and there is no build in graphical user interface to change parameters. The benefits to using this camera are: a manually adjustable aperture, the ability to easily change the lens, the ability to easily add a filter (i.e. polarizing filter, neutral density filter, color bandpass filter, etc.), and it can be mounted securely with bolts (and still removed easily).

The lens that is being used with the new camera is the T 2314 FICS-3, also from The Imaging Source. This is a 2.3 mm focal length, wide angle lens. This lens allows a slightly greater field of view than the webcam with slightly less distortion. The camera was also tested with a 5 mm focal length lens, although there was almost no distortion, the field of view was inadequate. The distortion of the 2.3 mm focal length lens is acceptable by virtue of the software used on this vehicle (discussed below).

The camera mounting system was also improved. Last year's design included a piece of PVC pipe to house the camera and run the camera's cable. This PVC pipe was haphazardly supported by various pieces of angled

aluminum and hose clamps as can be seen in the above photo (left side). The positive sides of this design are that the camera is almost completely weatherproofed, the cord is conveniently run through the PVC pipe, and the angle of the camera can be easily changed. The disadvantages to this design are that the PVC pipe would shake as the vehicle moves (causing the images from the camera to be inconsistent) and the camera (housed inside the top horizontal section of PVC) was only held at a constant angle by friction between the PVC connections. Fixing these problems was a simple task and it significantly improved the vision system. The new mast system includes a 1.5" square hollow aluminum tube (30" long) held to the platform by 3 90° angle brackets with bolts that go through the wooden deck. On the top of the tube is a bracket from 80/20 Inc., part number 4319 (also attached with bolts). The L-shaped piece that connects the camera to the bracket was fabricated by the Naval Academy Machine shop. This design is superior because it allows the operator to change the angle of the camera, if desired, and once a position is decided, it can be tightened down so that the camera will not move. The final selection puts the camera 140 cm above the ground, pointed down at an angle of approximately 60°. The main disadvantage to the new system versus the old is that it is not inherently weather proofed; however, an umbrella can be used to serve this purpose.

b. Software

After acquiring images we preprocess by: thresholding to obtain a binary image, and applying morphological filters to reduce noise.

Images are first transformed to the HSV (Hue, Saturation, Value) color space due to its relative invariance with respect to ambient light levels. Information from the saturation and value channels is used to threshold white objects from the green grass creating a binary image. In order to filter out small specks of ground that resemble the lane marking color, a morphological opening is applied to the image.

In order to accomplish controlled lane following, after finding candidate line segments in the image we relate pixel locations to points in space defined relative to a vehicle fixed reference frame. This was accomplished by first calibrating the camera to obtain its intrinsic and extrinsic parameters. We use a second order distortion and pinhole camera model. We then assume all the objects seen by the camera are in the ground plane.

Under the assumption that everything in the image is in a single plane (the ground plane) we can recover depth information. It is reasonable to assume that the lane markings will be in the ground plane; however, many objects will not be in the ground plane and estimated position of these objects would be inaccurate. This does not pose a problem to the vehicle because it is the laser system that is used to avoid such obstacles.

We located the vehicle coordinate frame at the center of the laser range finder. To relate the frames, we placed two calibration objects that would be in the view of the laser and the camera. Identifying the position of the two objects in both the camera and laser frame, allowed us to relate the frames (since we only want to work in two dimensions and with the assumption that the planes are parallel). After this was completed we had the ability to feed in pixel coordinates and get the two dimensional position in the body frame.

Generally, the Hough Transform [3] can be used to try to find any parameterizable line or shape in an image; however, the shape does not need to be perfect. The idea of the Hough Transform is test fit many possible

combinations of the parameter values. For each pixel that concurs with a given parameter combination a “vote” is given to that combination. Thus, the goal is to find where these votes peak to determine the most likely parameter description of the shape that is being searched for. A common way to represent the searching of a line is to use two parameters, representing its orientation and distance from the origin. The implementation used consisted of the following techniques and parameter values:

Thresholds: Saturation < 20%, Value > 75%

Morphology: Open with a 5x3 rectangular structural element (a morphological opening is an erosion followed by a dilatation in order to remove small area, non-connected, noise in the image).

Reconstruction: Camera Calibration Tool Box [2]

Hough Transform: implementation is the one included in MATLAB 2008A [3] with the following parameter options:

- RhoResolution = 1
- ThetaResolution = 2
- NHoodSize = [301 21]
- Threshold = 100
- NumPeaks = 2
- FillGap = 20
- MinLength = 40

Design Evaluation

a. List and Describe All Metrics

During the design process, the team estimated there to be three metrics associated with the performance of the laser system, easy to modify, avoid obstacles, and repeatability, but after completion we considered a fourth, easy to monitor:

Easy to Modify

Criteria: (1) access parts, (2) change modes, (3) modify code

- 4- Meets all criteria and can address each individually
- 3- Meets all criteria but other functions may be affected
- 2- Meets 2 of 3 criteria
- 1- Meets 1 of 3 criteria
- 0- Cannot meet any of the criteria

Quick to Initialize

Criteria: Per IGVC R&R, must be initialized within 2 minutes

- 4- Initialized with single mouse click or command

- 3- Initialized in 30 seconds
- 2- Initialized in 1 minute
- 1- Initialized in 2 minutes
- 0- Initialization takes longer than 2 minutes

Easy to Monitor

- 4- Data logging and remote real-time monitoring
- 3- Data logging and real-time monitoring
- 2- Data logging only
- 1- Real-time monitoring only
- 0- No data logging and no real-time monitoring

Weather Proof

- 4- Weather-proofing incorporated in platform
- 2- Temporary weather-proofing available
- 0- Not weather-proofed

Emergency Stop

Criteria: Per IGVC rules and regulations, must have a manual and remote emergency stop

- 4- Reliably meets criteria 100% of the time
- 0- Does not meet criteria

Follows Lanes

- 4- Always stays within lanes
- 3- May deviate from lanes but self-corrects before fully exiting lane
- 2- Can follow lanes when with 45 degrees of robot's current course
- 1- Can only follow lanes when lane is straight and parallel to robot's current course
- 0- No lane following capability

Avoid Obstacles

- 4- Can avoid any obstacle 100% of the time
- 3- Can avoid any obstacle in one horizontal plane
- 2- Can avoid any obstacle in one horizontal plane 80% of the time
- 1- Can avoid any obstacle in one horizontal plane 50% of the time
- 0- No obstacle avoidance capabilities

Stability

- 4- Maintain upright stability and traction on any terrain, up to 15 degree slope or bank
- 3- Maintain upright stability and traction on a slope up to 10 degrees
- 2- Maintain upright stability and traction on slope up to 5 degrees
- 1- Maintain upright stability on any reasonably level terrain
- 0- Unstable on any terrain that is not flat and level

Repeatability

- 4- Vehicle behaves in same manner for multiple successive runs of a given scenario
- 3- Vehicle behavior has minor inconsistencies but still has the same net result for a given scenario
- 2- Vehicle behavior has inconsistencies that contribute to a different net result for a given scenario
- 0- Vehicle behavior is inconsistent to nearly random

b. Evaluate Specified Metrics

- Robo-Goat earns a four for Easy to Modify, all of the criteria were fulfilled.
- On Quick to Initialize, the robot again earns a four.
- On Easy to Monitor, the team only earns a one, no improvements were made to the design in this regard; however, it continues to output real time data on command.
- For Weather Proof, the systems has built in protection from the elements, so this is a four.
- The Emergency Stop performs up to specification; therefore this is a four as well.
- For the metrics relating to “Avoid Obstacles” we achieved a “3” in that we avoid obstacles 80% of the time.
- The metrics established for following lanes do not lend themselves to simple classification based on the limited testing that has been performed.
- Stability earn a 3. Robo goat has not been tested on a 15° bank, therefore we cannot determine if a four should be awarded.
- More testing is necessary to determine a score for repeatability.
- More detailed explanation of the metrics relating to the laser system are explained here:

For “Easy to Modify” the laser system definitely achieved a “4”. For “Easy to Monitor” we achieved at least a “1” in that we have real-time monitoring by watching the figure displayed on the screen for each scan, and have the capability to log the series of desired headings and best headings, as well as speed limiting percentages, because these are all easy accessible variables. However, without remote desk top monitoring like envisioned earlier, it is easier to follow real-time monitoring behind the vehicle by watching the figures.

Our metrics for “Avoid Obstacles” are not reflective of the various levels the vehicle can achieve obstacle avoidance, in that the concern with one plane namely stemmed from a nodding laser. While the laser only seems obstacles in its plane, it is low enough to see even the shortest of anticipated obstacles at the

competition. As is, the criteria for “4” should be eliminated and the subsequent criteria move up one point. Therefore, we achieved a “3” in that we avoid obstacles 80% of the time. The biggest difficulty with this aspect is finding a threshold small enough to allow the vehicle enough time to turn away from an obstacle but not so large that everything is an obstacle and so it slows down going straight.

Barring the unexplained failure of our first laser, the vehicle behavior has minor inconsistencies but still has the same net result (in that it will avoid the obstacle). Depending on the approach to the obstacle sometimes the vehicle may pass it to the left or right. Thus we achieved a “3”. To truly test repeatability we will have to test the laser in a larger variety of environments. So far all the testing and driving has taken place inside, in Maury Hall and Bancroft Hall.

c. Demonstration Plan

To demonstrate the use of the laser, there are two options: to test solely the laser’s plan of avoidance without engaging the wheels and to engage the wheels and watch the vehicle avoid obstacles. For the first, a short script, *continuous.m*, was created to establish a *while* loop to provide continuous feedback as the vehicle is manually manipulated. For the second, *DriveWLaser.m* can be run. If the program is ever interrupted or aborted however, but MATLAB does not close, do not run the program from the beginning; instead, evaluate only the second cell. When this program is integrated into *MasterPlan.m* this will not be a problem because all the initializations happen in a separate script. Essentially, only the second cell is incorporated into *MasterPlan.m*.

To check the effectiveness of the changes to the body, the vehicle was weighed before and after the modifications. It was found that the total weight of the vehicle dropped by 33 lbs. Due to the fact that all of this weight was in the upper section of the vehicle, the center of gravity dropped (how much if too difficult to determine). When the new upper section was put on the vehicle, it was mounted forward of where the old section was mounted. The center of gravity moved forward, but it is difficult to determine how much. The real test for the altered center of gravity was when the vehicle was placed on a ramp of about 15° and it did not tip back on the “wheelie bars” as it would have in the previous design.

To truly test the weather resistance of the vehicle further testing must be done. Electronic components should be removed, and the vehicle should be at first lightly sprayed with a hose, progressing to an equivalent of hard rain.

d. Overall Design Critique

Overall, the design performs well but there are definitely improvements to be made. One of the biggest problems last year, clipping obstacles due to not enough lateral clearance to allow for body of vehicle to pass unimpeded, has been almost entirely mitigated. All the code is extensively commented so it should be easy for future IGVC teams to follow the logic and expand upon it. Additionally, there are specific messages displayed on the screen so if there ever is an error it will be easy to debug the script files. Currently the vehicle can handle complex obstacles such as switchbacks and center dead ends, but has not been tested on anything like a pothole. Depending on the size and depth of the pothole, if the vehicle is on a decline and the laser starts to return of the ground it is facing, the scan will likely show no gaps and slow until it stops or the E-Stop is triggered. For next year,

recommended improvements include estimating velocities using the laser, developing local area mapping, further fine tuning of the angular velocity output, and finding away to have a graphical output printed to the screen without significantly slowing the code down.

Costs

Parts	
Description	Totals
Body Work	
Aluminum Frame	\$0
Wood Decks	\$0
Aluminum Mast	\$0
Camera Mount	\$49
Plexiglass	\$0
Weatherstripping	\$20
Shocks	\$102
Caulk	\$10
Total Body Parts:	\$181
Hokoyo Laser (1):	\$2500
Camera Lens (1):	\$113
Camera (1):	\$460
Total Parts:	\$3254

References

- [1] <http://www.acroname.com/robotics/parts/R283-HOKUYO-LASER1.html>
- [2] Bouguet, Jean-Yves. "Camera Calibration Toolbox for MATLAB."
<http://www.vision.caltech.edu/bouguetj/index.html>
- [3] Matlab R2008A, "hough.m", The Mathworks 2007
- [4] IGVC Rules and Regulations. <http://www.igvc.org/rules.htm>