Eighth Annual International

Ground Vehicle Competition

Design Report

ALVIN

Trinity College

Hartford, Connecticut

July 8, 2000

1. Introduction

ALVIN, a four-wheeled autonomous vehicle, is the first-generation result of a semester's work to design and build a robot to compete in the International Ground Vehicle Competition (IGVC). A team of four undergraduate engineering students from Trinity College in Hartford, CT designed and built the vehicle .

ALVIN's name is an acronym whose meaning is a fiercely guarded secret, derived from the animated television series *Alvin and the Chipmunks*. The robot described in this report is Trinity College's first entry in the IGVC, and is representative of a minimalist design approach: minimal budget in minimal time.

1.1. Features

ALVIN prides itself on efficient design. The overall cost of the robot, excluding donations is under US $3,000. With donations, it is under US $8,000. Due to material and equipment constraints outlined below, The entire ALVIN system with payload weighs approximately 100 pounds. The key to this is wireless communication. Alvin can be controlled/monitored/debugged wirelessly, removing the need for a monitor and computer accessories on board.

2. Design History

The ALVIN project is a part of a one-semester capstone senior design course. The task division was in 3 parts: Mechanics and Propulsion, Computers/Sensors and Integration and Vision and Navigation. With 4 team members (all EEs), the budget is that of pooled resources for individual projects, faculty grants and donations. The donations from the following sources helped to make ALVIN a reality and also dictated the course of the design.

Motorola	**332- microcontroller board**
Imaging Technologies	**Capture Card**
Intelligent Motion Systems	**Motors and Controllers**
Kucka Enterprises	**Misc**
Eckart and Finard Fastener Specialists	**Fasteners**

2.1. CAD Tools

AutoCad was the primary mechanical layout package used to develop ALVIN. It aided with component placement as well as prototyping other design alternatives. Windraft was used as the primary electrical schematic layout package. Power Systems and some electronics were done in Windraft for the design and documentation phases of the project. Altera’s MaxPlus II software was used to develop a Programmable Logic Device (PLD) based interface for Ultrasonic Sensors. The design was fully simulated using Altera’s VHDL simulator and schematic capture.

Matlab and Maple were used for Mathematical modeling and some simulation in the ALVIN design.

3. Body and Drive System Design:

Initial design criteria were established as a basis for vehicle mass, dimensions, and drive system to match the specifications of the donated motors.

- Vehicle, without required 20 lb. load, was to fall within the range of 50–70 lbs. (22.72–31.81 kg.).

Vehicle size should fall just within required dimensions for AUVSI contest guidelines.

- Length - 3 ft.
- Width, Height - Unspecified
- Vehicle propulsion and steering is accomplished using a four-wheel drive system incorporating bilateral motor drive. Differential and skid-steering is implemented for motion control.

3.1. Body Design:

Weight was a key factor in frame design. To adhere to AUVSI contest guidelines, the minimum length of the vehicle had to be greater than 3 ft. 6061-T6 Aluminum extruded square tubing was used for design of the frame because of its light weight, strength, price, availability, and ease of machining. Perforated aluminum sheets were also used to provide platforms where needed.

In order to accommodate all of the systems mentioned above while simultaneously minimizing the dimensions of the vehicle, a multi-tier design was decided upon. The speculated differences of the power requirements and ‘noise’ (EMI) of the computer and drive system, determined the placement of systems on each tier.

The spacing on the first tier of the vehicle accommodated all power, drive systems, and the 8 x 8 x 16 load. The second level was designated for the computer and possible VESTA board to control the drive system. The second tier also served as a platform for mounting a tripod for the CCD camera of the vision system.

AutoCAD LT was employed as a tool to aid system design. The vehicle had to be designed from 2-D models due to the constraints of the program. AutoCAD proved quite useful to aid the planning of placement and interaction of the vehicle frame and acquired parts.

3.2. Drive System:

Four 12” recumbent bicycle wheels were acquired for the vehicle. These wheels matched specifications as well as being made of an aluminum alloy to aid in the weight minimization initiative. The wheels came with quick-release mechanisms to aid in vehicle assembly. Using bicycle gear to minimize respective chain and gear weights limits the possible gearing solutions to those sizes of manufactured gears.

A 13:44 gear ratio was implemented using standard 13 and 44 tooth bicycle gears. The 13-tooth served as the motor gear and the 44-tooth gears directly attached to the wheels.

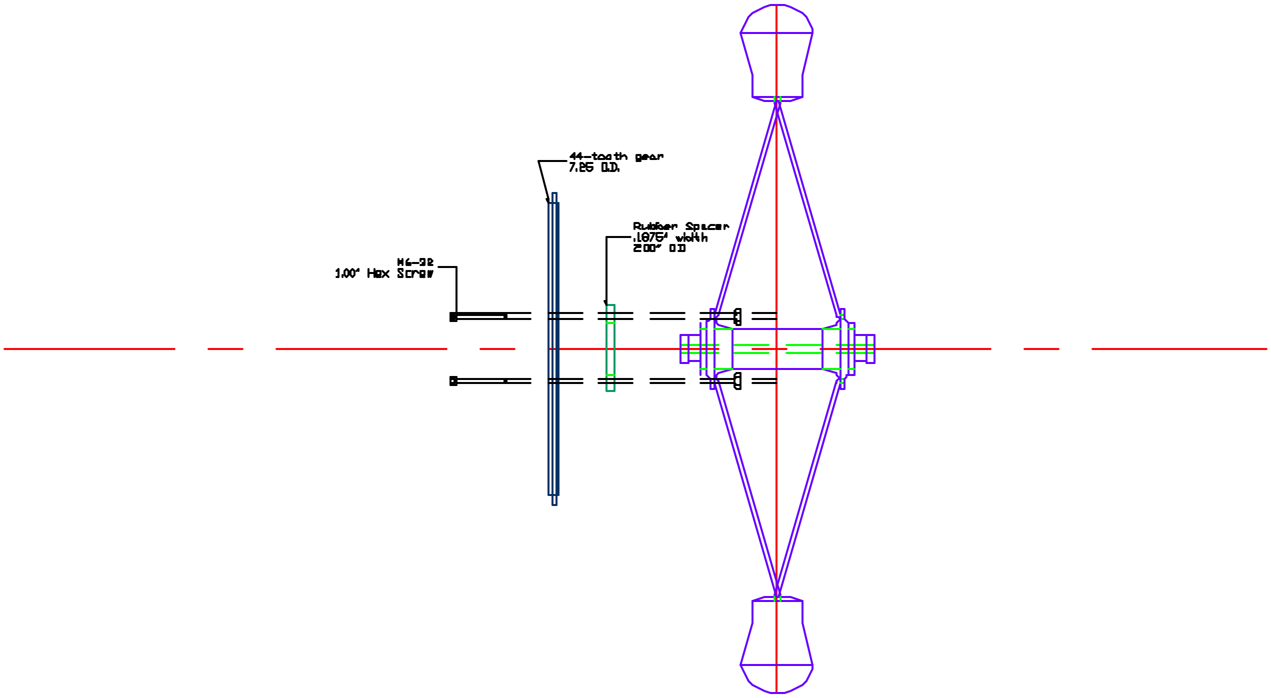

Figure - 1. *Wheel gear assembly*

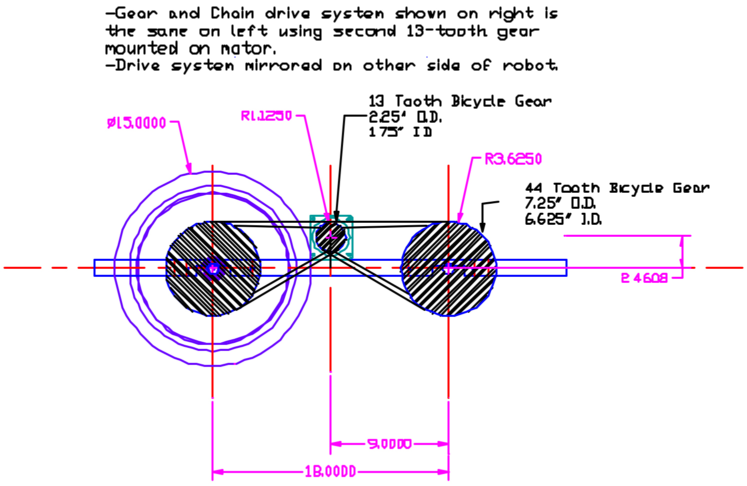
-Gear and Chain drive system shown on right is the same on left using second 13-tooth gear mounted on motor.
-Drive system mirrored on other side of robot.

Figure 2.: *Schematic of vehicle Drive System*

Standard bicycle chain, ½" x $^{3}/_{32}$", was used. ½" indicating the pitch and $^{3}/_{32}$" indicating the internal width of the chain. The chain length was calculated using the following formula:

3.3. Motors & Motor Control

Properly sizing the motors required a number of initial conditions and assumptions to be made:

Initial conditions

- Probable range of vehicle weight
- Change in vehicle speed
- Distance in which ΔV occurs
- Wheel radius known
- Gear ratio known

Assumptions

- Linear acceleration assumed
- No slippage occurs during acceleration or deceleration

With the conditions and assumptions listed above the following model was created to estimate torque required for the motor. The torque values generated by these equations reflect the worst-case scenario for decelerating the vehicle from initial speed v_i to rest $v_f = 0$ mph.

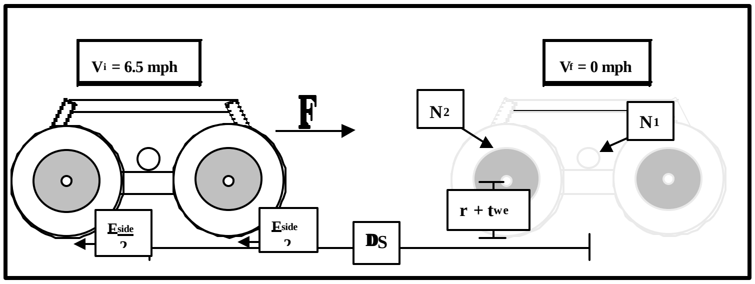

Figure - 3. *– Diagram of forces applied to body*

<u>Calculations Used To Calculate T</u>

$$v_i - v_f$$

$$a = \frac{\Delta v^2}{2(\Delta s)}$$

$$F = ma$$

$$F_{Side} = F / 2$$

$$T_{Side} = F_{Side} * (r_{wheel} + T_{we})$$

$$T_{Motor} = T_{Side} * \frac{n_1}{n_2}$$

$$W(rad/\sec) = W_{RPM} * \frac{2p}{60}$$

$$\mathrm{P}_{\mathrm{rot}} = T * W$$

The chart of motor torques was generated using the above equations in conjunction with MATLAB. The specifications for the motor were based upon the to torque required to stop the motion of a vehicle with the following criteria:

$m = 80$ lb
$\Delta v = 6.0$ mph
$\Delta s = 3$ ft.
$n_1 = 13$ teeth
$n_2 = 44$ teeth
With these values $T_{max} = 568.93$ oz-in.
With $\Delta v = 5.0$ mph; $\Delta s = 3.0$ ft; $\mathbf{T_{op}} = 395.10$ oz-in

holding torque, $T_{\text{holding}} = 620$ oz-in. $T_{\text{holding}} > T_{\text{max}}$. M 2-3450 is the lightest motor with the ability to supply the needed torque.

As motor rotations increase, available torque of the motor decreases. Therefore, it is also necessary to know the operational torque of the motor at maximum operation conditions. The following are rotation per second estimates of the wheel at five miles per hour.

(**Note**- Size 34 1.8° hybrid stepping motors have 200 steps per rotation.)

RPS Estimate

$$v = 5mph = 7.33\ {}^{ft}\!/\!{}_{s} = 2.235\ {}^{m}\!/\!{}_{s}$$

$$C_{wheel} = \boldsymbol{p}(D_{wheel} + T_E) = 47.12\ in. = 1.20\ m$$

$$Rotations/_{s}\ {}_{(WheelGear)} = v / C_{wheel} = 1.867$$

Given the gear ratio from above

$$Rot/_{s}\ {}_{(Motor)} = \frac{n_2 * \frac{rot}{s}}{n_1} = 6.32\ {}^{rot}\!/\!{}_{s}$$

$$Rot/_{s} * Steps/_{Rot} = 1264\ \text{Steps}/_{Sec}$$

Using the graph of the Speed/Torque Curve for the motor, the available motor torque at 1264 RPS ≈ 450 oz-in.

Supplied with the M 2-3450-S were two IM1007 microstepping drives for the motors. High output current, 14 microstep resolutions, on the fly microstep switching and single power supply for motor controller and motors.

3.4. System Weight:

Specifications of the vehicle weight were estimated before construction of the body and components as well as integration of the systems. Estimation of the vehicle weight was also an extremely important variable in the deciding the torque requirements of the motors. It was necessary to accurately estimate (within 25% of the extremes of system capacities) the weight of the system to allow consistent non-stressful operation of the motor. The following table is an initial estimate of system component including the required system load.

Component	**Unit Weight**	**Quantity**	**Total**
Body	15.0	1	15
Wheels	3.00	4	12
Computer	7.00	1	7.0
Motors	8.00	2	16
Batteries	7.00	3	21
Misc	10.0	NA	10
Subtotal			81
Load	20.0	1	20
Total			101

Table-1: *Revised initial system weight.*

With the majority of parts necessary for the completion of the robot, it was possible to accurately estimate the weight of the completed robot. Doing so allows in-construction changes of materials necessary to minimize system weight.

4. Electrical/Computer Design

4.1. Power System

The system as a whole requires a large amount of power in order to service the main computer, VESTA board(s), motor controllers, and motors. The power systems were separated based upon current requirements and noise factors. The motor controllers have wide voltage and current inputs and the supply power to the motors. The computer systems however require highly regulated voltage and current supplies to ensure safe operation.

In addition the power supply of the computer requires 115-120VAC at 60 HZ. Connecting batteries to an inverter was more feasible than using a UPS because of weight interconnection issues.

Motor power requires 36 volts, achieved by connecting three 12 V power sources in series. Given that each motor requires 3-5 A current to operate, ~30 – 60 minutes of vehicle runtime can be achieved with battery ratings of 8 – 10 amp hours.

Sealed Lead-Acid batteries are the least expensive alternative of the three. 12 volt batteries are readily available with different Amp hour voltages. In the comparison test the best possible power solutions had weight:Amp-hour ratios with values less than .800. Ni-Cad ratio comes in at .638 and Ni-MH ratio is .577. Given the motors are connected in series the DD1270 or Panasonic LC-P127R2 would be obviously the best choices to minimize weight and provide 20-40 running times.

Batteries were light enough to be easily removed. Multiple sets of batteries were used for continuous runs and constant charging. There was little down time with testing using this method.

Sensors

4.2. Short Range Sensors:

Infrared seemed to be the obvious choice for the design of the short-range sensors. However, since the robot will be traveling at speeds approaching 5mph, it was realized that if an object were within one foot, there would be little chance of avoiding it. Consider the scenario when the robot is running at the top speed of 5 mph or 7.33 fps. If the braking distance is 2.5 ft, by the time an IR device detects an object 3ft away and braking is initiated, the robot would stop 6 inches short of the obstacle assuming there is no skidding. This does not leave much room for navigation. IR sensors would not be efficient for the IGVC. In light of this, short-range sensing was deemed unnecessary for the purposes of this robot.

4.3. Long Range Sensors:

The sensor used for ALVIN, the Polaroid 6500, is capable of detecting an object from within a foot to up to 65 feet away. The Polaroid 6500 was chosen primarily because of its availability, low cost, and reliability.

Ultrasonic ranging devices are based upon sound reflection. Sound travels at approximately 2 ft in 1 ms. Using the echo for distance ranging, this translates to approximately 1 ft per ms. Microcontrollers are comparatively fast with respect to the speed of sound. The distance ranging accuracy increases tremendously by using microcontrollers for the timing. Resolutions of about 1/hundredth of a millisecond are reasonable for timing. The typical reliable range for an Ultrasonic Device is about 35 ft.

Figure ***4.*** *– Mounted ultrasound sensor array*

4.4 Control Systems Design:

The IGVC challenge demands the following for successful completion:

- High Performance OS
- Vision System
- Distance Ranging
- E-stop
- Sensor Interfacing Capabilities

These demands are answered with the following:

Microsoft Windows NT 4.0:

Windows NT 4.0 is becoming the mainstream business desktop operating system for all users. Window NT Workstation 4.0 offers the lowest TCO of any desktop platform while delivering unmatched performance and reliability. With Microsoft propaganda aside, Windows NT has proven to be a reliable industrial OS for real-time applications. It is more reliable than other spin-offs of Windows in terms of process management and file system. Also, the capture board for the vision system was designed to run under NT, adding weight to the decision.

VESTA OS:

Vesta Technology Inc. develops programmable controllers, for use in embedded systems, machine control, and OEM industrial applications. These tiny, powerful computers are based on the PIC16C62, PIC1674, 80C188EB, and 68332G processors, and come in a variety of models depending on the system level resources (such as memory and ports). We also offer custom configurations for production quantity orders.

A built-in VAST (Vesta Addressable Synchronous Transfer) interface allows controllers to communicate with a wide variety of off-the-shelf parts as well as a VESTA selection of common peripherals. There is also a PC/104 bus for faster I/O throughput. Vesta Embedded controllers require very little power and come with various sleep modes, so they're well suited for battery operated devices.

Vesta Basic Integrated Development Language is an excellent tool for creating embedded control systems. The SBC2000-188 and SBC2000-332 boards can be programmed also in C/C++ and assembler.

Vesta Technologies' IDL serves as the development platform for the inaugural version of ALVIN. Although programming is done in BASIC, which is a drawback for more advanced data structures, it is the hardware that will be the savior. The BASIC IDL is tremendously less expensive than the C++ compiler and it offers recursion capabilities. The VESTA systems come loaded with the following accessories:

- VAST I/O Bus
- ADC
- Digital I/O
- Serial Ports
- TPU
- Power Save Modules
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The VAST Bus is a modified IIC Bus that interconnects all peripherals. It simplifies adding and removing of components. The separate TPU provides timing for the ultrasonic array and PID control of the drive system. The serial port provides the basis for communication with the PIII.

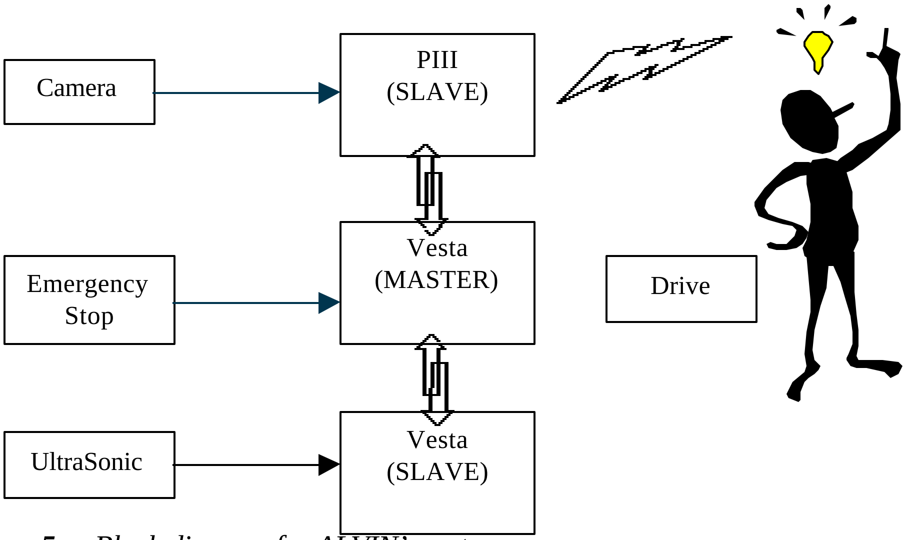

Figure ***5.*** *– Block diagram for ALVIN’s systems*

4.5. Computer System

ALVIN's vision system software can only run in Microsoft Windows NT, so a computer capable of running the operating system was necessary. In addition, the intense calculations required for navigation required a relatively powerful processor. To meet these needs, an Intel Pentium III 550 processor was selected for its processing power and relatively low cost.

ALVIN's onboard computer is run by an Intel Pentium III 550 processor mounted on an Asustek P2B-B motherboard with 128 MB of SDRAM.An ATI Xpert@Play 98 video card was used for its TV-out capabilities and a 3com Fast Etherlink III Ethernet card was used to network ALVIN to development computers.

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Figure ***6.*** *– Pentium III 550 (left), and ASUS P2B-B (right)*

5. Vision System

The camera used for the vision system is housed close to the center of ALVIN about 3 ft. off the ground. The PCVision video capture board is housed on the onboard computer attached to the second tier on ALVIN.

The camera plugs in straight into the PCVision board and all necessary software is also installed in ALVIN. The Pentium III system with the capture board, the camera and the UPS forms the vision system on it. Communication with the two other modules, namely, the sensor array and the motor control module is achieved through the serial ports.

5.1. ALVIN Kinematics Simulator:

Since most of this semester, which was devoted to outdoor ALVIN testing, produced bad weather and also because the body and the drive mechanism is not complete, Amir came up with the idea of simulating the kinematics of ALVIN on a computer.

A real time perspective image of the obstacle course was then displayed on a desktop computer. The perspective image was the expected scene to be seen from ALVIN. The computer also took in control signals outputted from the ALVIN computer via the serial port. It used this control signal to produce the expected response of ALVIN and the resulting change in scenery.

A camera was then positioned in front of the desktop computer and the perspective image displayed on the computer's screen was filmed like it was the real scene. Fig. 46 shows this ingenious concept in action.

The vision tool used was Sherlock. The application for lane following and obstacle avoidance is being developed using Sherlock and will be coded in C++ later.

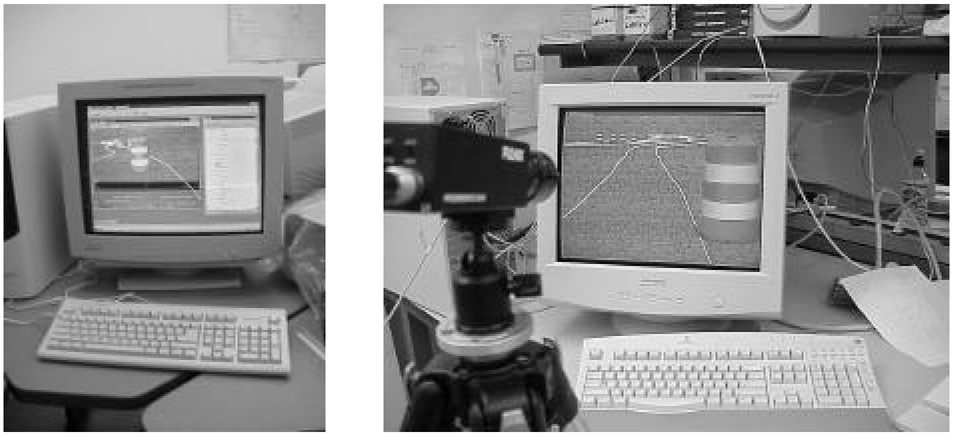
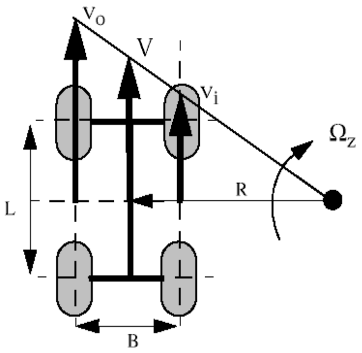


Figure 5 - Shows the image captured by the camera and being processed in Sherlock.

The Visual Basic program that simulates the motion refreshes the screen at about 20Hz.(every 50ms). The capture time for PCVision is 50ms per frame and Sherlock takes up more time for processing. Hence the simulation is valid.

5.2. ALVIN Kinematics:

The kinematics analysis of skid steering allows a preliminary determination of wheel velocities, given the vehicles dimensions, the desired radius and the desired turn rate. The model used here is not very accurate because it does not take into account the slippage that occurs. This is unfortunate because skid steering involves a lot of skidding. Nevertheless, it is good enough for our purpose.



Variables:

v_o = outside wheel velocity [m/s]
v_i = inside wheel velocity [m/s]
V = vehicle velocity [m/s]
Ω_z = vehicle angular velocity [rad/s]
R = vehicle turn radius [m]
L = vehicle length [m]
B = vehicle width [m]

Figure 8 - ALVIN skid steering kinematics

The equations can thus be derived as follows:

$$R = \frac{B}{2}\left(\frac{v_o + v_i}{v_o - v_i}\right) \text{and} \quad \Omega_z = \frac{v_o + v_i}{2R} = \frac{v_o - v_i}{B}$$

If we desire to go at some average velocity and also produce a differential to turn, this differential is limited by the fact that the electric motors can only provide so much torque. This puts an upper limit to the outer wheel velocity,

V_{OMAX}.

Thus in order to maintain the average velocity, the inner wheel velocity has to be = 2 V_{OMAX}. – V

This also puts an upper limit to the angular velocity about the center of the turn. This model was thus used to simulate the kinematics of ALVIN.

5.3. Lane Following:

Figure 7 shows not very clearly how the lane following has been achieved from the system. The long black rectangle seen in the image is the rectangle under investigation. Several preprocessing filters have been used on the image including equalizing and thresholding. The two lane markers are then detected in the two halves of the rectangle.

With the basic notion that the vehicle has to move parallel to the road in order for it to successfully stay within the track, the line was projected out into the horizon. The intersection of this line with the horizon has to occur at the same place as the intersection of the line through the center of the robot. Since the line through the center of the robot, is always the line in the center of the image, the intersection has to happen close to the center of the screen. Failure to do this would signal a vehicle going off track and corrective measures would have to be applied to bring the vehicle back on track.

If both lines of the track cannot be seen at some point, it is ok to rely on just one line with the argument above. When both lane markers are invisible, it is wise to hold the bearing until the tracks become visible again.

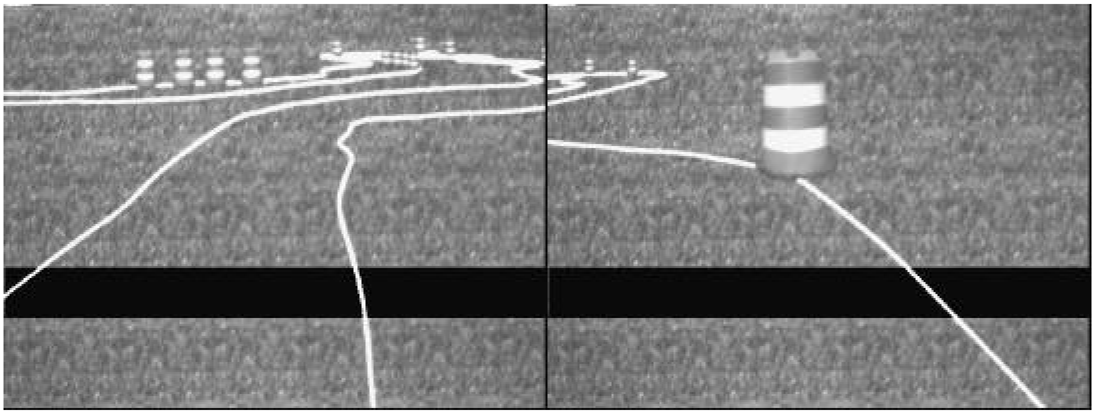


*Figure***7.** *- Lane following*

6. Other

Other features the ALVIN crew deem to be important and indispensable:

6.1 Safety

E-Stop: Although a requirement

Wireless Kill Switch