

**THIRTEENTH ANNUAL  
INTERNATIONAL GROUND VEHICLE COMPETITION**



# ALVIN-VI

## Design Report

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### Faculty Statement

This is to certify that ALVIN-VI has undergone significant redesign in both hardware and software from last year's IGVC entry. The ALVIN team members worked on the robot as an Independent Study project and received 1.0 credit (3 credit hours) per semester. This project is significant and has led to many senior design projects in both Computer Science and Engineering.

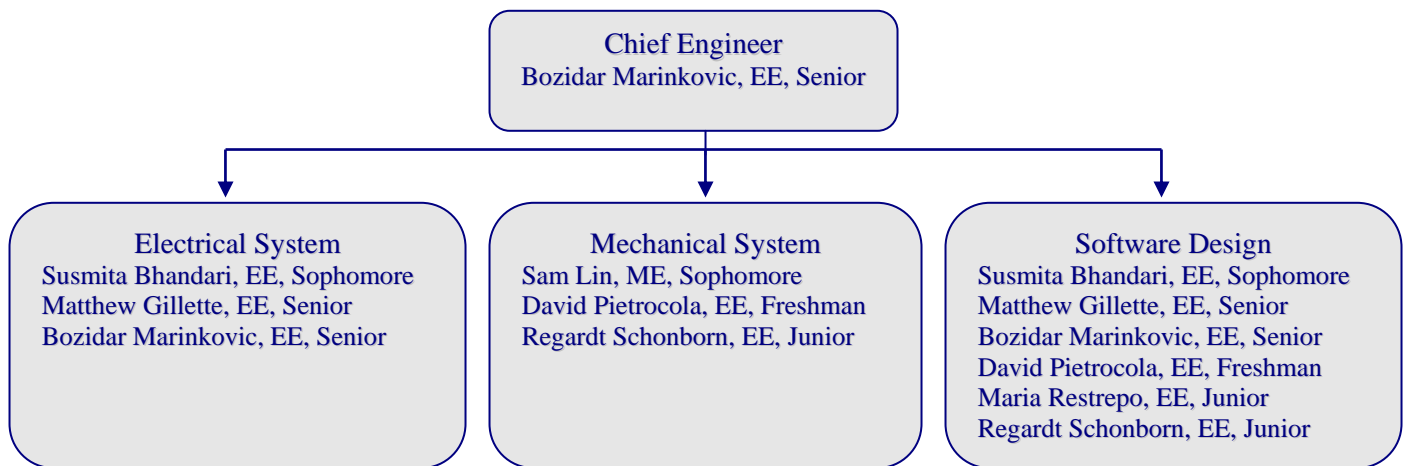
Dr. David J. Ahlgren,  
Karl W. Hallden Professor of Engineering, Trinity College

## 1. Introduction

ALVIN-VI is the sixth generation autonomous ground vehicle from the Robot Study Team (RST) of Trinity College. It incorporates many important design concepts of engineering, cutting-edge technologies and innovative software design. It has been a platform for the RST members to work as a part of team in developing and harnessing their technical and design skills. As such, this project has been an important part of their learning experience.

## 2. Team Organization

The RST consists of students from all levels of undergraduate study. They represent different fields of engineering; namely, electrical, computer and mechanical engineering. This year's team organization is shown below.



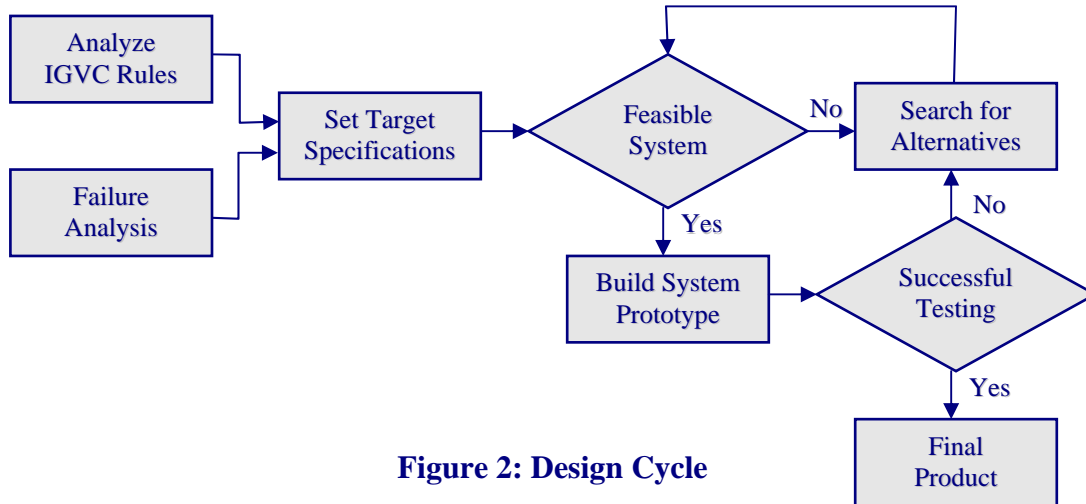
**Figure 1: Team Organization Chart**

As the overview above shows, the RST members are involved in different aspects of design and implementation. The team formally met twice a week, once on Wednesday for an hour and once on Sunday for about two hours to discuss progresses made and problems encountered. In addition, each team member devoted countless hours into this project. Overall, about 1600 person-hours were spent in the development of ALVIN-VI.

## 3. Design Process

The engineering design process for ALVIN-VI begins with analysis of consumer needs and previous performance of the robot. The targeted groups of consumers are IGVC judges, project advisor, and sponsors of IGVC.

The consumer needs are fully described by the competition rules and they are integrated together with failure analysis into target specifications for the new ALVIN-VI robot. Figure 2 shows the steps taken during the design of ALVIN-VI:



**Figure 2: Design Cycle**

#### 4. Target Specifications

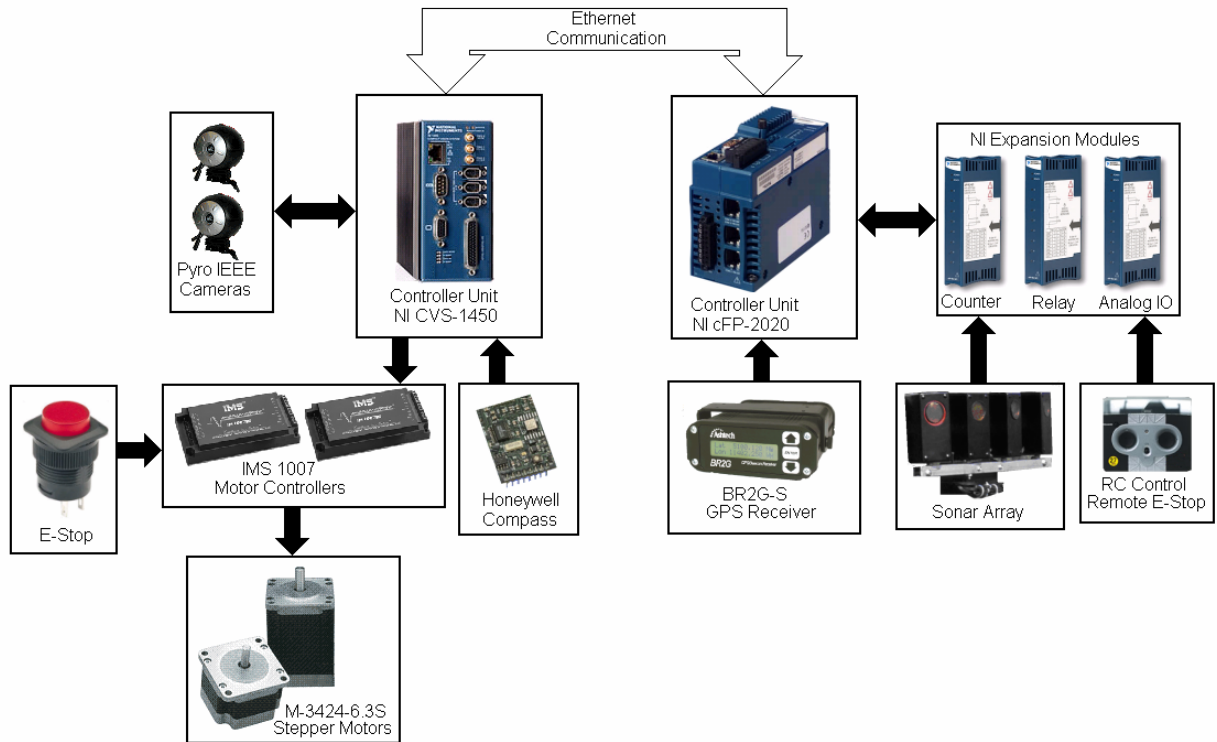
In the previous versions of ALVIN some of the problem areas were power system and drive system, as well as autonomous challenge algorithm. From the failure analysis and careful testing, the following specifications were deemed necessary for a successful performance of ALVIN-VI.

**Table 1: Target Specifications for ALVIN-VI**

<b>Weight</b>	<ul style="list-style-type: none"> <li>▪ 89lb including 20lb payload</li> </ul>
<b>Dimensions</b>	<ul style="list-style-type: none"> <li>▪ 3ft x 1.5ft x 2ft</li> </ul>
<b>Frame and Cover</b>	<ul style="list-style-type: none"> <li>▪ Frame: light weight aluminum tube</li> <li>▪ Cover: light weight aluminum sheet</li> </ul>
<b>Sensory System</b>	<ul style="list-style-type: none"> <li>▪ Camera: Two Pyro IEEE 1394 web cams</li> <li>▪ GPS: Ashtech BR2G-S GPS receiver</li> <li>▪ Compass: Honeywell Digital Compass HMR 3300</li> <li>▪ Ultrasonic Sensors: four Polaroid 6500 ranging modules</li> </ul>
<b>Drive System</b>	<ul style="list-style-type: none"> <li>▪ Motors: M2-3424 Stepper Motors</li> <li>▪ Motor Controller: IM1007 Micro stepping controllers</li> <li>▪ Gearbox: NE34-01 10:1</li> <li>▪ Wheels: two 16" wheelchair wheels</li> <li>▪ Belt Tensioners</li> </ul>
<b>Power Supply</b>	<ul style="list-style-type: none"> <li>▪ Motors use two UltraLife 30V Lithium Ion batteries</li> <li>▪ System uses Bosch 24V, 2.4 Ah NiCad battery</li> </ul>

## 5. System Integration Overview

The components on ALVIN-VI were organized so that they are easily accessible. All the sensors are attached to one of the two NI controllers which share data through the standard internet TCP/IP protocol. The figure below shows the overall system integration diagram for ALVIN-VI.



**Figure 3: Overview of System Integration for ALVIN-VI**

The next few sections provide a detailed description of the electrical, sensory, mechanical, and power systems in ALVIN-VI.

## 6. Electrical System

### 6.1 NI CVS-1454 Compact Vision System



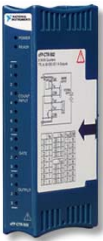
This module takes input and processes images from 3 IEEE-1394 cameras. This module also has one RS-232 port, 15 digital inputs and 14 digital outputs. It is used to interface with compass and motor control lines. The compact field point communicates with this module via an Ethernet port.

### 6.2 NI cFP-2020 Compact FieldPoint



This is the main controller of the robot. The FieldPoint has a RS-232 serial port, RS-485 port, LED indicators and programmable DIP switches. The FieldPoint Module interfaces with the GPS receiver and CVS. It has an Ethernet port and a removable CompactFlash to store data.

### 6.3 NI cFP-CTR 502 Counter Module



This counter device features 8 independently programmable counter inputs (16bit), 4 gate inputs and 4 digital outputs. The counter inputs and outputs operate at voltages higher than 12[V]. The counter currently uses 24[V] as operating voltage level. This module is used to interface with sonar sensors by measuring the time of flight of sound.

### 6.4 NI cFP-RLY-421 Relay Module



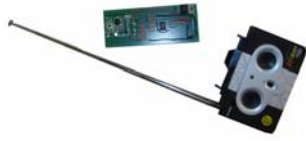
The NI relay module features 8 electromechanical relays which are able to switch up to 120VDC and can draw up to 1.5A. All the relays are independent of each other and can be programmed separately. This module is used to control the power supply for the electrical components on ALVIN-VI.

### 6.5 NI cFP-AI-100 Analog Input Module



The analog input module can be programmed to measure low and medium voltage and milliampere current signals. It has eight inputs with 12-bit output resolution. This module is used to interconnect the remote control and control switches on the front panel of ALVIN-VI.

## 6.6 Remote Control



The remote control is radio frequency based control and serves the purpose of remote e-stop. It has also been configured to steer the robot when it is in stand by mode. The circuitry consists of resistor and op-amp network to convert digital lines to analog. The two analog inputs from the remote control then go to the analog input module. A simple LabVIEW interface was written to establish communication between the remote control and motor control. The output of this interface sends turning angle and sharpness to the motors. The remote control has an effective distance of 50 feet.

## 7. Sensory System

### 7.1 Vision System

The vision system on ALVIN-VI consists of two IEEE Pyro cameras. The cameras are attached to custom made mounting devices that allow adjustment of the camera heads in both vertical and horizontal directions with 90° of freedom. Cameras are connected to NI Compact Vision System CVS-1450 through the IEEE-1394 ports.



The CVS module has capability to concurrently grab images from three firewire cameras. ALVIN-VI uses the YUV-4:2:2 image format with resolution of 640x480 pixels. Images are streamed at relatively high frame rate of 15 [frames/sec]. The image processing results are sent to the main controller via ethernet connection available on CVS.

### 7.2 Ultrasonic System

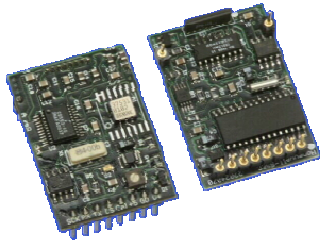
ALVIN-VI features an ultrasonic sensors array interfaced with the NI counter module (cFP-CTR-500) for the purpose of obstacle detection. The array consists of four SensComp/Polaroid 6500 ranging modules in the custom-built housing. Each sensor is able to measure distances from 6 inches to 35 feet with accuracy of  $\pm 1\%$ .



The echo signal from the sonar is set HIGH during the time of flight of sound. By measuring the HIGH intervals on this signal

with NI counter, it is possible to determine the exact distance from the objects. The operating voltage for the sonar modules is 5[V] while the input gates on the NI counter respond to the signals higher than 12[V]. Therefore, the signals from the NI module to the sonar sensors are stepped down from 24[V] to 5[V] and signals from the sonar sensors to the NI counter are amplified to 24[V].

### 7.3 Compass



The Honeywell HMR-3300 digital compass is a perfect orientation sensor for an autonomous vehicle. It provides very accurate azimuth angle with incline compensation. In addition the sensor provides tilt and pitch data in the range of  $\pm 60^\circ$ . The compass is interfaced with NI CVS module through the standard serial port.

### 7.4 Navigation System (GPS)

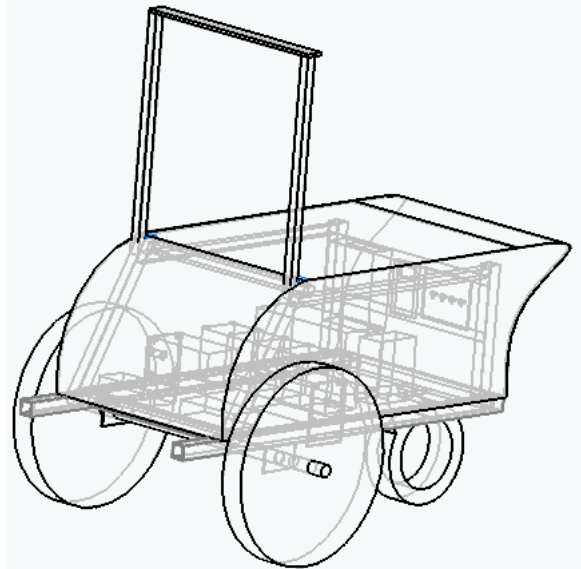


ALVIN-VI is equipped with an Ashtech BR2G-S GPS receiver, which provides differential GPS position with reliable sub-meter accuracy. It combines the dual-channel beacon receiver technology with the industry standard Ashtech 12-channel precision GPS, integrated in a single, easy-to-use product. The second part of the navigation system is the GPS antenna which is mounted on a carbon fiber rod above robot case to ensure clear view to the open sky. The GPS receiver is setup to send data to the NI cFP controller via standard serial port.

## 8. Mechanical Design

### 8.1 Body and Case

The main target specification during the design of ALVIN body was low weight. To achieve this objective the body of ALVIN was built using light aluminum tubing, while the cover was mainly shaped out from thin aluminum sheets. The cover was carefully designed to provide easy access to all critical components such as the batteries, control panels, and network ports for communications with the NI controllers. Water proofing was done along the aluminum edges to keep the components safe in case of inclined weather. In



**Figure 4: Solid Works Design of ALVIN-VI**

addition, the aluminum body serves as a solid heat sink for overheating electrical components.

The robot features raised support structure with a purpose to carry two cameras, the sonar sensor array, and the compass. It was determined that this design allows the best placement of sensory systems.

### 8.2 Drive System

The main components of the drive system are two high torque stepper motors. The IMS IM3424 stepper motors provide ample torque and speed at an 18.3:1 gear ratio. The motors are controlled by the FPGA chip integrated into the NI CVS module via two IMS IM1007 micro-stepping motor controllers. This configuration enables easy software control over the motors directly from the LabVIEW program running on the CVS controller.

During the failure analysis of previous ALVIN designs, it was recognized that the problems occurred when the axel between two wheels began to bend. Therefore, the ALVIN-VI drive system was designed with two 16" wheelchair wheels completely independent from each other. The wheels connect to the motor gears through the Phil Wood racing hubs which were directly mounted onto the robot using sturdy aluminum blocks.

## 9. Power System

During the failure analysis of previous versions of ALVIN it was recognized that power supply was very unstable and unreliable. The problem was approached by designing new power system for the robot. The project consisted of two parts: development of the stable and reliable power supply unit, and rewiring the power distribution of all the components on ALVIN. The first step was analysis of power consumption, which is summarized in the following table.

**Table 2: The Power Consumption for ALVIN-VI**

<b>COMPONENT</b>	<b>CURRENT [A]</b>	<b>VOLTAGE [V]</b>	<b>POWER [W]</b>
Two IMS M-3424-6.3S Motor	6 x 2	60	720
NI CVS-1454 Vision System with Two Pyro IEEE Cameras	1.5	24	36
NI cFP-2020 Controller With Two NI Modules (counter and relay)	1	24	24
Ashtech BR2G-S (GPS Receiver)	0.5	12	6
Honeywell Compass (HMR-3300)	0.02	12	0.24
Four Polaroid 6500 Ranging Modules	0.5	5	2.5
Total Power Consumption			788.74

The motors on ALVIN-VI are powered by two Ultralife Lithium-Ion, 30[V], 6[Ah] batteries. These batteries are specially designed for military use and are robust. The rest of the electrical system is powered by one 24[V], 2.4[Ah], NI-Cd battery, designed by BOSCH for use with the handheld drills. The battery is lightweight, powerful and has very quick recharging time of one hour.

The power supply module was designed using CAD software, and manufactured and assembled in the laboratory. Required potential levels were obtained with the use of DC-DC converters which can take a range of unregulated input voltages to produce steady voltage output. The whole design was based on “star architecture”, where all the ground lines on the robot were connected together at one point. Special care was taken to minimize any potential noise problems through proper grounding techniques and use of capacitors.

The testing of the power supply unit was done by connecting it to maximum potential load and running it continuously for 24 hours. The supply proved to be stable and it was mounted on the robot.

## 10. Software and Control Strategies

### 10.1 Drive Control

Drive control for ALVIN-VI consists of two major components: high-level motor driver and low-level motor driver. The high-level motor driver is setup to receive the turning angle and sharpness of the turn for the robot. This information is then processed and converted to corresponding speeds for the left and right motor and forwarded to the low-level motor driver. The low-level motor driver uses the FPGA to generate proper pulse streams and control bits for the external motor controllers. The feedback signals are utilized for error correction. Following is the block diagram of drive control software.

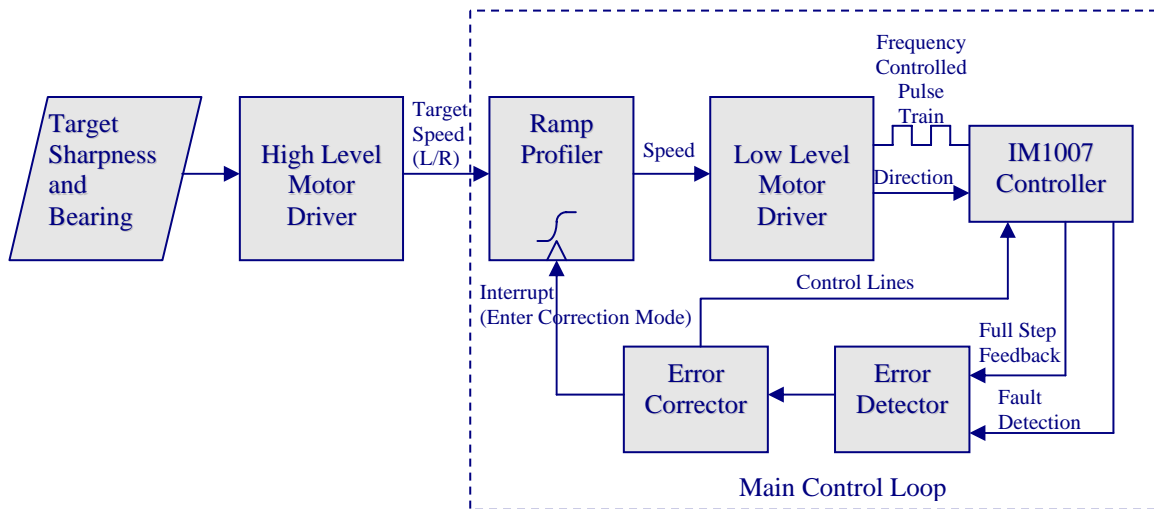


Figure 5: Motion Control with an Error Correction

### 10.2 Obstacle Avoidance

Obstacle avoidance is performed using the sonar sensor array. The four sonar sensors form the four zones in front of the robot weighted as the four digits of the base three numbers. Also, the three distance thresholds are setup as danger areas where each area is assigned the number from zero to two. Multiplying the danger area number with the corresponding zone weight and adding the four results together can generate a unique state number to give a representation of the obstacle arrangement in front of the robot. The state number is run through the lookup table which stores the turn angle and turn sharpness for each possible obstacle arrangement. The state number is also used to identify the traps and dead ends. The lookup table approach was chosen because of its simplicity speed and reliability.

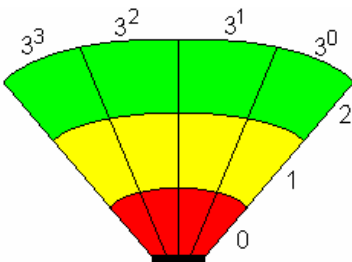
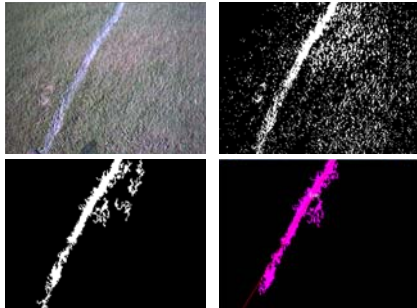


Figure 6: Polar Grid

### 10.3 Line Detection

The lines are extracted from the images obtained by two fire wire web cameras. The raw images are passed to NI CVS controller where the image processing is performed to extract the



**Figure 7: Image processing**

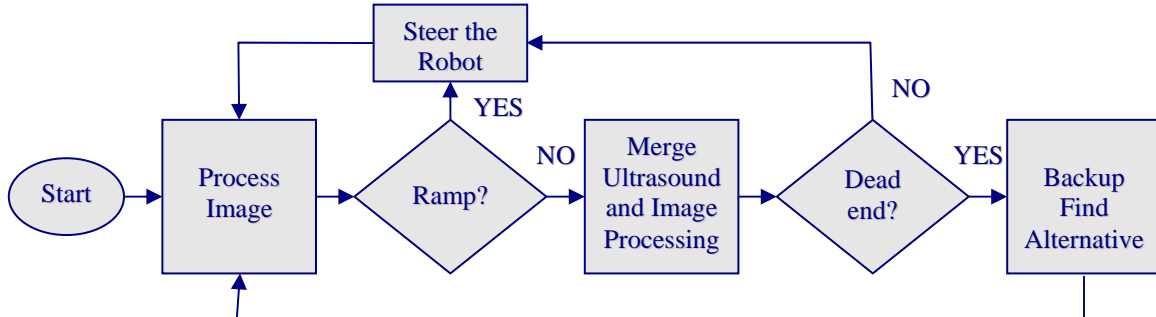
lines, detect potholes and recognize the presence of a ramp. The image processing algorithms was developed using National Instruments IMAQ Vision Builder which is highly compatible with LabVIEW programs.

The image processing algorithms utilize hue, saturation, and luminance of an input image. In addition, the image is passed through a number of low pass and particle filters to

reliably extract lines and potholes. The thresholds for filtering are determined through the statistical analysis of the input image. The ramp is recognized by its specific smooth texture.

### 10.4 Autonomous Challenge

The autonomous algorithm is based on the state machine architecture. The input information is received from the compass, cameras and sonar sensors. Following is the state diagram.



**Figure 8: Autonomous Navigation State Diagram**

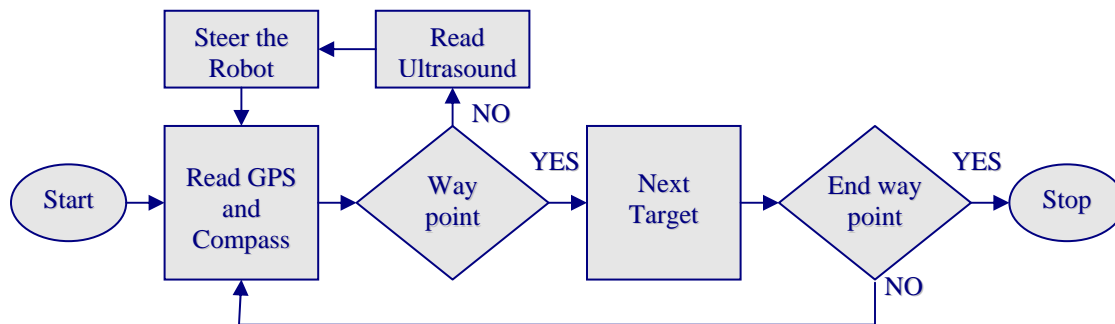
All data acquisition and motor steering processes run simultaneously with the state machine. The multitasking arrangement ensures that the decision-making is continuously updated with newest data from the sensors and that the motor controllers continuously receive new adjusted commands.

The information from two cameras and the ultrasound array is merged into a larger and finer polar grid with six zones and four danger areas (similar to figure 6). A state number is generated and run through the lookup table as in previously described obstacle detection. The turning angle and sharpness are then sent to the high-level motor driver for steering the robot.

It was determined that the 6x4 polar grid is sufficient to steer the robot of ALVIN-VI's size accurately enough. Also, the lookup table approach provides a fast, simple and reliable solution for autonomous navigation.

### 10.5 Global Positioning System Navigation Challenge

The GPS navigation algorithm utilizes the state machine architecture as well. The input to the state machine is the processed data from the sensors, while the output is the turning angle and turning sharpness for the robot. As in autonomous software, the data acquisition is run simultaneously with state machine. Following is the state diagram for the GPS controller.



**Figure 9: GPS Navigation State Diagram**

Both, the path planning and reactive algorithms are used in the state machine. The path planning uses the current vehicle position, its heading and the target position to calculate how much the vehicle has to adjust itself in order to go straight toward the target. When the obstacle is detected the path planning gets suspended and the ultrasound array is used to maneuver the vehicle around the obstacles.

## 11. Performance Prediction and Analysis

**Table 3: Table of Predicted and Tested Results of ALVIN-VI Performance**

Performance Areas	Predicted Results	Tested Results
Robot Navigation	Complete the Course in 9min	N/A
Battery Life	Motors: 1h, System: 2h	Motors: 45min, System: 1h 35min
Speed	4.5[mph] Maximum, 2[mph] Typical	Actual Maximum 4[mph]
Ramp Climbing Ability	15 degrees	15 degrees
Stopping Distance	2[ft]	3[ft]
Dead ends and traps	Back Up Until a Successful Path Found	N/A
Potholes	Accurately Detected and Avoided	N/A
Waypoint Accuracy	1[m]	1[m]

## 12. Safety Considerations

The safety concerns have been given the outmost priority in ALVIN-VI. This is clear from the proper wiring of the components of the vehicle and the use of chassis as the common ground. The custom designed power supply also ensures safety of the electronic components by its use of circuit breakers to limit the current from exceeding 2[A]. In addition, the control panel on the side of the robot serves as a safe interface to operate the robot.

The batteries used in ALVIN-VI are self-contained and safe. The lithium ion battery used for motors contains internal protection circuit that shuts off the battery if the current exceeds 18[A]. This feature provides an extra safety measure. Also, during start up, the motors produce a current spike, which causes the lithium ion battery to shut off. After some testing, it was found that inrush current limiters decrease the current spike significantly. This has brought more safety to the vehicle.

The stopping of the robot is another safety consideration. ALVIN-VI can be stopped in three ways, each of which can bring the robot to a complete stop within two feet distance. One way is to use the red e-stop push button on the rear end of the robot. Another method is to use the remote control to wirelessly stop the robot during its run. The effective distance for this method is 50 feet. The last method is the use of the on/off switch on the control panel. All three methods are safe and accessible for use.

### 13. Cost Analysis

The table below shows the cost breakdown for the construction of ALVIN-VI:

**Table 4: Cost Breakdown**

<b>COMPONENTS</b>	<b>RETAIL COST (\$)</b>	<b>COST INCURRED (\$)</b>
Pyro IEEE Cameras(2)	180	180
Polaroid 6500 Ranging Modules(4)	180	180
Frame	40	40
Aluminum Sheet	50	50
Wheel Chair Wheels	350	350
Wiring	50	50
Gears and Belts	250	80
IMS M-3424-6.3S Motors (2)	230	0
IMS IM1007 Controllers (2)	910	0
NI LabVIEW Developer Suite	4295	0
NI LabVIEW IEEE Drivers	990	0
NI LabVIEW Vision Dev. Module	2595	0
NI CVS-1454 Vision System	2995	0
NI cFP-2020	1895	0
NI cFP-CTR-502	425	0
NI cFP-RLY-421	250	0
NI cFP-AI-100	425	0
Ultralife 30V Lithium Ion Batteries (2)	770	0
Bosch 24V Nickel Cadmium Battery	190	0
Honeywell Compass (HMR-3300)	750	0
Ashtech BR2G-S (GPS Receiver)	3350	0
Remote Control	50	50
Power Supply Board	150	0
<b>Total</b>	<b>21370</b>	<b>980</b>

### 14. Sponsors

- Bosch Corporation
- Bayside Motion Group
- Connecticut NASA Space Grant Consortium
- Honeywell International Inc.
- Intelligent Motion Systems Inc.
- National Instruments
- PCB Express
- Thales Navigation
- Trinity College
- Travelers Insurance
- Teknicircuits Inc.
- Ultralife Batteries Inc.
- Enterprise Rent-A-Car