TWELFTH ANNUAL
INTERNATIONAL GROUND VEHICLE COMPETITION

ALVIN-V

Design Report

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Statement From Faculty

This is to certify that ALVIN-V 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,
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1. Introduction

This report documents the development of the fifth generation of unmanned Intelligent Ground Vehicles, ALVIN-V, from the Robot Study Team (RST) of Trinity College. ALVIN-V has emerged as a technically superior vehicle from its predecessors, incorporating many new features and at the same time improving the old features. Throughout the evolution cycle of ALVIN generations, RST has endeavored to incorporate engineering research and design, experimentation, development and presentation of results in its efforts. ALVIN-V, as such, represents a platform for the RST to present engineering design, innovative concepts in software design, technical skills acquired and teamwork.

2. Team Organization

Within the RST, the ALVIN-V project has its own sub-team of students specializing in electrical and mechanical engineering, and computer science. The ALVIN-V team members comprise of students in their senior year to freshmen, providing each with an opportunity to learn skills beyond classrooms. With the rest of the RST, the ALVIN-V team enjoyed a supportive framework of intellectual exchange with brainstorming sessions, meetings and presentations.

Table 1: ***ALVIN-V Team Members***

Name	Class Year	Specialization
Nhon Trinh	2004	Chief Engineer, Vision System, Sensor System
Michelle Bovard	2004	Team Leader, Mechanical Design, CAD
Trishan deLanerolle	2004	Navigation System, Public Relations
Peter Votto	2004	Mechanical Design, CAD
Matthew Gillette	2005	Vision System, Drive System, Electrical Systems
Bozidar Marinkovic	2005	Navigation System, Sensor System, Electrical Systems
Kevin Harder	2006	Mechanical Design
Susmita Bhandari	2007	Testing and Simulation

The team members met every Wednesday afternoon for a general meeting and Sunday afternoon for team meeting. These sessions typically involved discussions on work in progress, generation of new ideas, problem solving, work allocation and presentations to name a few.

3. Design Process

As we geared for entering the 12th Annual Intelligent Ground Vehicle Competition, we overviewed the performance of ALVIN-IV in last year's IGVC. ALVIN-IV's performance in Navigation Challenge was undermined by the placement of the sensor array, which caused the robot to identify an uneven terrain as an obstacle. Yet another limitation was put forward by the heating of Vesta motor controller resulting in a number of run losses. We identified these problems with ALVIN-IV and addressed them by introducing changes on the electrical, software and sensory systems and mechanical design. Integrating together all the components of the robot also became our goal for ALVIN-V.

The flowchart below documents the steps taken in the during the design of ALVIN-V:

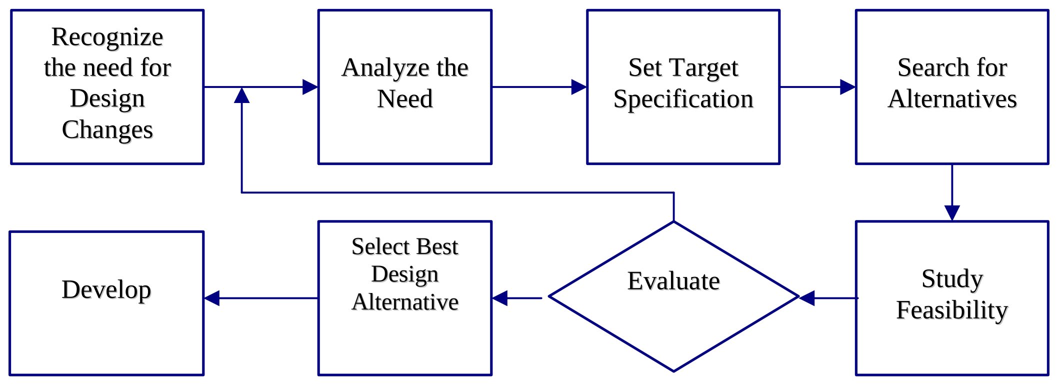


Figure 1: Design Cycle

Listed below are major design changes implemented on ALVIN-V:

- **Compass**
  The navigation code that we use depends on reliable compass readings. One of the drawbacks of the compass used by ALVIN-IV was it could not compensate for tilt and hence on encountering an incline, it failed to give correct readings. The old compass has been replaced by new Honeywell HMR3300 digital compass.

- **Control System**
  The master-slave concept incorporated in ALVIN-III and ALVIN-IV has been replaced completely by National Instruments hardware, providing greater control of the robot along with increased speed and less circuitry.

- **Power System**
  The power failure before and during runs due to the running out of batteries was a major problem for ALVIN-IV and its predecessors. ALVIN-V uses Lithium Ion and Nickel Cadmium batteries that have longer life and can provide more power.

- **Motor Control and Drive System**
  ALVIN-IV's run also saw limitations on motor control and drive system resulting in lack of control and slow speed. Extensive motor testing was done to ascertain the factors limiting speed. It was found that the motor itself was powerful enough to handle more speed but the gear ratio needed to be changed and belt tensioners needed to be added to prevent the belts from slipping.

4. Target Specifications

After a considerable amount of time spent in analysis of previous years' performances followed by identification of design changes necessary, we developed target specifications for ALVIN-V.

A comparative view of the specifications of ALVIN-IV and target specifications of ALVIN-V follows.

Table 2: ***A Comparative Look at Specifications***

Target Areas	ALVIN-IV	ALVIN-V
Weight	▪ 99lb including 20lb payload	▪ 89lb including 20lb payload
Dimensions	▪ 3ft x 1.5ft x 2ft	▪ 3ft x 1.5ft x 2ft
Vehicle Frame and Cover	▪ Frame: light weight aluminum tube ▪ Cover: light weight molded plastic	▪ Frame: light weight aluminum tube ▪ Cover: light weight molded fiber glass
Sensory System	▪ Camera: Two Pyro IEEE 1394 web cams ▪ Software: NI LabVIEW 6.1 ▪ GPS: Ashtech BR2G-S GPS receiver ▪ Ultrasonic Sensors: four Polaroid 6500 ranging modules	▪ Camera: Two Pyro IEEE 1394 web cams, National Instruments (NI) Compact Vision System CVS-1450 ▪ Software: NI LabVIEW 7.0 ▪ GPS and Navigation: Ashtech BR2G-S GPS receiver, NI Compact FieldPoint module, Honeywell Digital Compass HMR 3300 ▪ Ultrasonic Sensors: four Polaroid 6500 ranging modules
Drive System	▪ Motors: M2-3424 Stepper Motors ▪ Motor Controller: IM1007 Micro stepping controllers ▪ Gearbox: NE34-01 10:1 Gearbox ▪ Wheels: Bicycle Wheels in front and Pneumatic Caster on the back	▪ Compact Vision System CVS-1450 ▪ Motors: M2-3424 Stepper Motors ▪ Motor Controller: IM1007 Micro stepping controllers ▪ Gearbox: NE34-01 10:1 ▪ Wheels: Bicycle Wheels in front and Pneumatic Caster on the back ▪ Belt Tensioners
Power System	▪ Motor – Uses 12V, 5AH lead-acid cells ▪ GPS and Vesta – Use 9.6V, 1600mAh NiMH batteries ▪ 4 Ultrasonic Sensors – Use 9.6V, 700mAh NiMH battery	▪ Motor-Uses two UltraLife 30V Lithium Ion batteries in series ▪ All other systems run on a Bosch 24V, 2.4 Ah Nickel Cadmium battery
Vehicle Performance	▪ Maximum Speed: 3 mph ▪ Normal Speed: 1 mph ▪ Remote Stop capability: 1000 ft ▪ Minimum Stop Distance: 3 ft at a speed of 3 mph at an incline of 25 degrees	▪ Maximum Speed: 4.5 mph ▪ Normal Speed: 2 mph ▪ Remote Stop capability: 1000 ft ▪ Minimum Stop Distance: 3 ft at a speed of 3 mph at an incline of 25 degrees

5. Electrical System

Following are the NI modules that form the Control System of ALVIN-V:

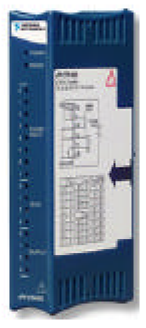
5.1 NI CVS-1454 Compact Vision System

This module takes input and processes images from 3 IEEE-1394 cameras with downloadable LabVIEW VI. This module also has one RS –232 port, 15 digital inputs and 14 digital outputs that can be used to interface with GPS, kill-switch, probe light, and IMS 1007 control lines (micro step resolution selects, direction, etc). Other components can communicate with this module via Ethernet port.

5.2 NI cFP-2020 Compact FieldPoint

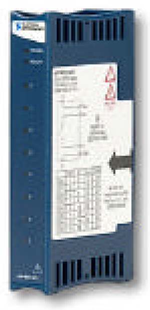
This is the central controller of the robot. The main LabVIEW VI with all the navigation intelligence compiles and downloads to this module. The FieldPoint has one or more RS-232 serial ports accessible through software. It also has LED indicators to communicate status information and DIP switches that perform various functions. The cFP-2020 also has a software-accessible RS-485 port and discrete input/output (DIO) terminals for connecting to external devices such as LED status indicators and start/stop buttons. The FieldPoint Module interfaces with the GPS receiver and compass. It has one Ethernet port, four serial ports, and removable CompactFlash to store data.

5.3 NI cFP-CTR 502 Counter Module



The NI counter device (cFP-CTR-500) features 8 independently programmable counter inputs (16bit), 4 gate inputs and 4 digital outputs. The counting source can be external signal, previous counter channel trigger, 1KHz or 32KHz internal reference. The counter can trigger associated output or next channel when it reaches the terminal count (setup by user). Additionally the counter can be gated using one of the gate inputs, which mean the counter will count only when the gate input is HIGH. The outputs can be used as general digital outputs or can be associated to the one of the counter channels to produce trigger pulse when the counter reaches the terminal count. The inputs of this device open at input voltage higher then 12 V, so by using 24 V supply the input signals lower then 12 V have been amplified to suit the device.

5.4 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. It was decided to use this module to control the blue strobe light because of its high current requirement.

6. Sensory System

6.1 Vision System

In conjunction with two IEEE Pyro cameras mounted on either side of the robot at an angle such that the minimum view is 1 meter with a 60-degree field of view on either side of the robot, ALVIN-V uses Compact Vision System CVS-1450. CVS-1450 is a product of National Instruments targeting at automatic inspection applications. It can run LabVIEW Real-time and has a wide range of different kinds of input and output lines.

CVS-1450 has three IEEE-1394 ports that can concurrently grab images from three firewire cameras. LabVIEW's image acquisition library NI-IMAQ allows configuring the cameras to output pixel data in different formats, as listed in the following table:

Table 3: ***Available Video Formats and Bandwidths***

Video Format	Frames per Second	Maximum Number of Cameras for Simultaneous Operation
640 x 480, 8-Bit/Pixel Monochrome	30	3
	60	1
	100	1
640 x 480 YUV (4:2:2) 16-Bit/Pixel Color	15	3
	30	1
1024 x 768 16-Bit/Pixel Monochrome	7.5	2
	15	1

The YUV 4:2:2 format with resolution 640x480 will be very useful the ALVIN's purpose because it allows grabbing images from all three cameras with a high frame rate of 15 frames / second. This frame rate will allow ALVIN-V to update its decisions more frequently and hence improve its navigation performance.

CVS 1450 comes with various types of digital I/O lines, including both TTL-compatible and isolated I/O. Some of pins also have special functions beyond general purpose I/O. CVS-1450 can be easily connected to other NI components as well as PC's via Ethernet connection running TCP/IP, which is available in standard library of LabVIEW 7.0. The module also has one RS-232 port available. CVS-1450 has 128 MB of SRAM and 32 MB of volatile memory to save program code.

Grabbing images using Compact Vision System is very similar to using a laptop in LabVIEW 6.1. The figure below is a Virtual Instrument (VI) used to grab and display images from a firewire camera.

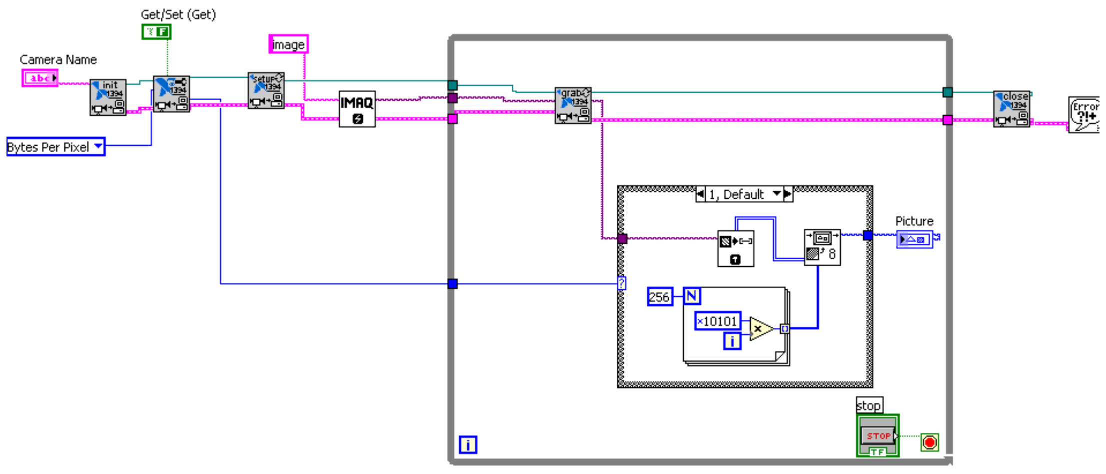
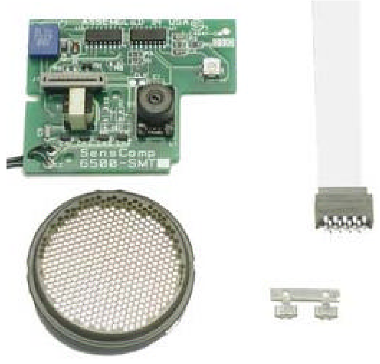


Figure 2: VI to grab and display images using CVS-1450

The firewire port is first initiated using “1394 Init”. Then camera is configured for grabbing images. The actual grabbing work is done inside a while loop controlled by a STOP button. After every loop, the newly acquired image is saved to an image buffer and is displayed on the screen. Pixel resolution is retrieved from the format of the camera so that colors of the images are mapped properly.

6.2 Ultrasonic System

ALVIN-V features an ultrasonic sensors array interfaced with the NI counter module (cFP-CTR-500). The array consists of four SensComp/Polaroid 6500 ranging modules in the custom-built housing and is able to scan an area of 120 degrees in front of the robot.

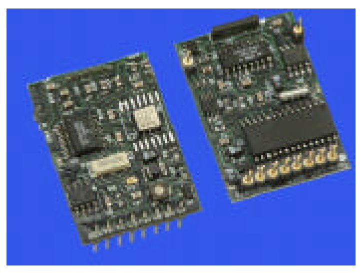


The SensComp/Polaroid 6500 module measures distances from 6 inches to 35 feet with an accuracy of ±1%. The module is able to differentiate echoes from objects that are only three inches apart.

The echo signal from the sonar is at HIGH level during the time of flight of sound. This signal was connected to gate input on the NI counter module. The counter channel was programmed to count at the rate 32 KHz while the gate input was “high” which enabled measure the time of flight of sound. Using the measured time of flight it was possible to calculate the distance of the obstacles.

The operating voltage for the sonar modules ranges from 4.5 V to 6.8 V. The input gates in the NI counter module open when the input voltage is higher then 12 V. It was decided to sue 24 V signals. Therefore the signals from the NI module to the sonar sensors had to be step down from 24 V to 5 V and signals from sonar sensors to input gates had to be step up from 5 V to 24 V. This was achieved using the custom-made interface board.

6.3 Compass



The Honeywell HMR-3300 digital compass is a good replacement for Devantech CMPS-03 used by ALVIN-IV because of its ability to provide incline compensation and tilt data, in addition to angle information. The additional tilt data provided by the Honeywell compass has been integrated into the navigation algorithms to provide better control. The HMR3300 is a three-axis, tilt compensated compass that uses a two-axis accelerometer for enhanced performance up to ± 60 degrees tilt range. A LabVIEW serial communication VI receives data from the compass.

6.4 Navigation System

ALVIN-V is equipped with an Ashtech BR2G-S GPS receiver, which provides differential GPS position accuracy and reliable user-friendly operation for the navigation challenge portion of the competition. It combines the latest dual-channel beacon receiver technology with the industry-leading Ashtech 12-channel precision GPS, integrated in a single, easy-to-use product that provides sub-meter position accuracy.

In addition to the GPS module the robot features Honeywell HMR3300 digital compass used to measure robots bearing. The GPS and compass readings are combined with the data from the ultrasonic sensor array and used in the path-planning algorithm. The final result from the path planning is in the form of the angle by which robot has to turn. This angle is further handled by the high-level drive control in order to turn the robot to predicted direction.

7. Mechanical System

7.1 Mechanical Design

New Body Case

The ALVIN-V all-weather cover was designed using the Solidworks software package. The cover was constructed using a semi-malleable wire mesh and polymer. The wire mesh was shaped using simple hand tools, and covered with the polymer composite matrix to create a weather-resistant cover for the electrical components. In addition to its weather-resistant properties, the cover serves as a temperature control device. The exterior of the cover is painted with a metallic paint in order to reflect the incoming thermal radiation from the sun, and the cover includes an airflow system to effectively cool the electrical components during operation. The airflow system is made up of fans set into the cover that direct fresh air from the environment over the electrical components, where they absorb heat, then back out to the environment.

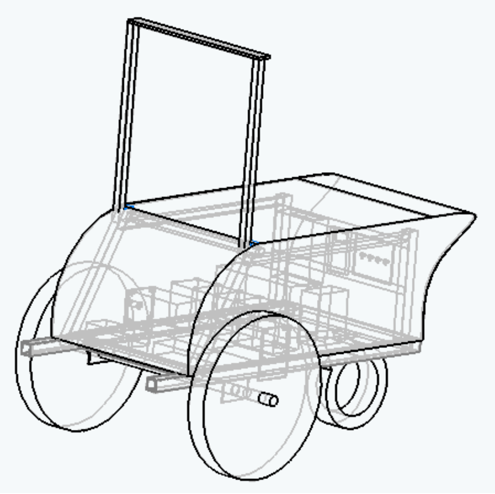


Figure 3: ALVIN-V SolidWorks Case Design

7.2 Drive System

Hardware

The motors and motor controllers are unchanged since last year. The robot still operates using IM3424 high torque stepper motors and IM1007 micro-stepping controllers. The motors drive 16” bicycle wheels using a belt train. After extensive torque and performance tests, the gear ratio was changed from 33:1 to 18.3:1 to increase the speed of the robot. Improved belt tensioners were also added to the drive system, as belt slipping was determined to be a major limiting factor in the performance of the robot, especially on inclines.

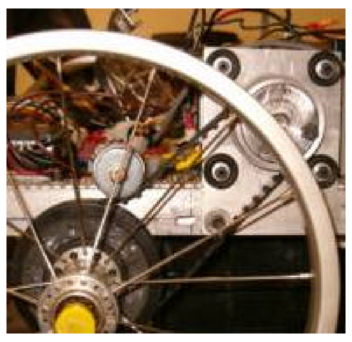


Figure 4: New Belt Tensioners and Gears

The most significant difference in the drive system and motion control of ALVIN-V is the removal of the VESTA single board computer. The motors are now driven using the National Instruments CVS-1454. The FPGA in the Compact Vision System is utilized to control TTL and optically isolated digital outputs and inputs to generate control signals and pulse trains required by the IM1007 micro-stepping controllers as well as receive step feedback from these controllers.

Control Strategy

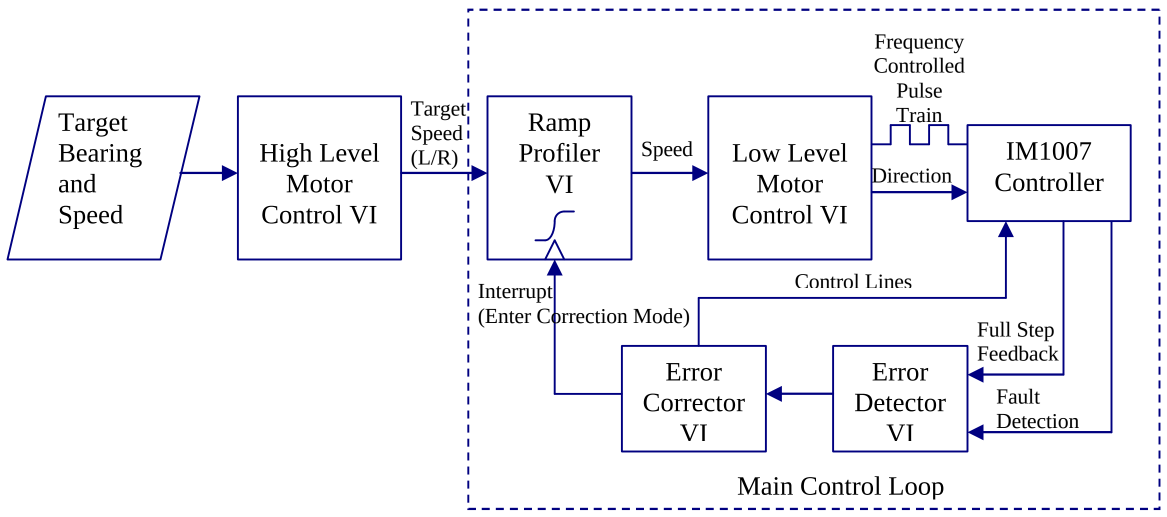


Figure 5: Motion Control with Error Correction

8. Power System

Another problem that was noticed in previous competitions was with the power system. In the past the robot has used a combination of five lead-acid 12 V, 5 Ah for motors and three Ni MH 9.6 V, 1.6 Ah to power other system components. There are several problems with this system:

lead acid batteries take long time to charge, they are heavy and contribute significantly to the weight to the robot, and there is large number of batteries to handle.

To determine a new power scheme for the robot, the power consumption needs for the whole system were thoroughly analyzed considering the new system components.

Table 4: ***The Power Consumption for ALVIN-V***

Component	Current [A]	Voltage [V]	Note
Two IMS M-3424-6.3S Motor	7	60	At normal speed
NI CVS-1454 Vision System with Two Pyro IEEE Cameras	1.5	21-27	Run at 24 V
NI cFP-2020 Controller With Two NI Modules (counter and relay)	1.5	11-30	Run at 24 V
Ashtech BR2G-S (GPS Receiver)	0.5	6-30	Run at 24 V
Honeywell Compass (HMR-3300)	0.022	6-15	Run at 12 V
Four Polaroid 6500 Ranging Modules	0.5	5	Time averaged

It was determined that Ultralife Lithium-Ion 30 V, 5.5 Ah batteries would make a good power replacement for the system. These batteries are used by the Military and are very highly rated. It was possible to obtain only two of these batteries, so it was decided to use the Ultralife batteries only for the motors instead of five 12 V lead-acid batteries.

Additionally, the team decided to replace three Ni-MH batteries with only one battery efficient enough to power all the other devices on board. Excellent replacement for Ni-MH batteries is BOSCH BAT031 24V, 2.4Ah Ni-Cd battery. The battery is lightweight (used in handheld machines) and able to power all the devices on ALVIN-V except the motors. The charging time for the battery is one hour.

9. System Integration

There has been a considerable hardware addition in ALVIN-V. The newly acquired NI hardware has enabled us to remove the laptop and Vesta board central to many generations of ALVIN. At the same time NI components have allowed increased processing speed and capacity. Integrating the new hardware with the electronic components already present in the robot required completely new wiring schematic and careful planning.

The NI modules along with the new HMR3300 digital compass needed to be integrated in ALVIN-V. The figure below shows the new configured control system for ALVIN-V.

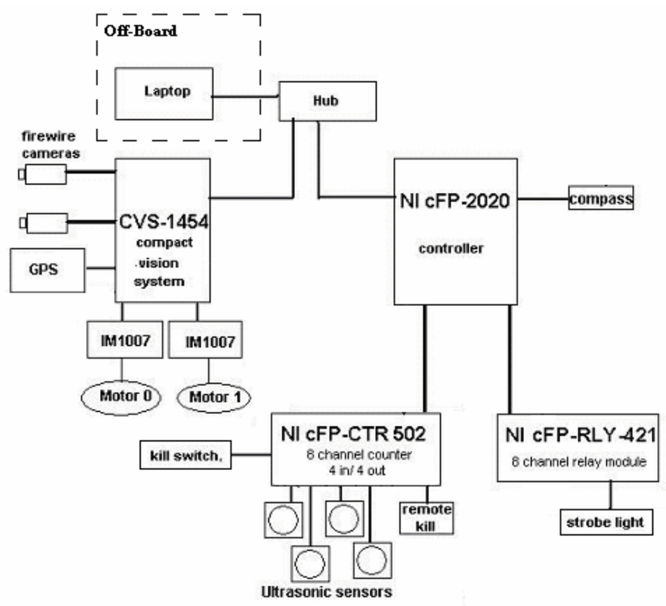


Figure 6: Control system based on NI hardware

10. Software and Control Strategies

10.1 Autonomous Challenge

The autonomous navigation algorithms, while similar to last years approach have some notable differences.

Vision System: Line, Pothole, and Ramp Detection

The vision system, consisting of the National Instruments CVS-1454 using two Pyro IEEE-1394 cameras is used to detect the lanes, as well as detecting potholes and the presence of the ramp. IMAQ Vision Builder, also supplied by National Instruments is used to generate image-processing algorithms to extract features of lines, potholes, and the ramp.

The image algorithms used utilize the hue, saturation, and luminance of an image grabbed from the cameras. The image is also passed through a number of low pass filters and particle filters to reliably extract images. Many image-processing algorithms have been developed under a variety of conditions. Further more, the LabVIEW code for the autonomous challenge can automatically switch through the algorithms generated using IMAQ Vision Builder if the algorithm currently in use fails.

Sonar Ranging System: Obstacle Detection

Four Polaroid 6500 ranging modules are used for obstacle detection. The ultrasonic sensors will detect obstacles up to 35 feet away. The sensors are calibrated such that the regions covered by each sensor will not overlap within 35 feet. When an obstacle is detected, it is plotted on a grid.

Data Integration and Path Planning

Data from the vision system and the sonar ranging system are integrated using a grid. Obstacles and lines are drawn on the grid using the data acquired by the sensors.

The first step in the path-planning algorithm is to determine “danger zones,” regions where the robot should not go. There are two types of danger zones, designated as “high” and “low” danger. These zones are first determined by the boundaries of the lane, these are designated as high danger zones; next, the zones are determined by the location of obstacles, also designated as high danger zones where obstacles are present. Other danger zones are determined by tracing rays from the origin through the map to each square on the grid not already designated as being a high danger. Calculating the distance of the line that passes through the high danger zones is used to determine whether or not the grid square should be designated as either high, low, or no danger zones.

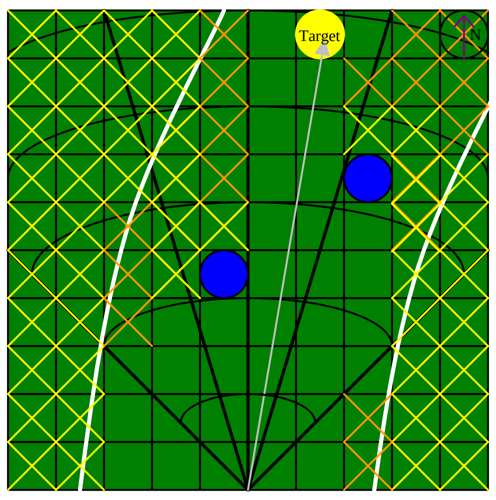


Figure 7: Data Integration and Path Planning

After determining which grid squares pose a danger to the robot, the target square for the robot is determined. This is done starting at the top row of squares, and searching for squares where no danger is present, row by row. The middle of the first no danger region found by the robot is designated as the target. If there is no region found where there is no danger, the robot will proceed to finding low danger regions. If there are no low danger regions, the robot will back up to attempt to determine another safe path. Once a target square has been determined, a vector is drawn from the origin to the target. The robot utilizes the direction of this vector to set it's bearing and also the magnitude of the bearing to determine a speed.

10.2 Global Positioning System Based Navigation Challenge

The problems with unreliable readings on the incline encountered with Devantech CMPS03 compass on ALVIN-IV led to the change of the compass for ALVIN-V. The Honeywell HMR3300 was a good replacement and it was used in conjunction with the Ashtech BR2G-S GPS receiver. All the information data from the sensing equipment was imported into the LabVIEW via the RS-232 communication ports. The data was processed by the LabVIEW program and the steering commands were sent back to the motor controllers.

The navigation algorithm utilizes the combination of the state machine and multitasking. All decision-making processes and the information evaluation are synchronized by the state machine. Following is the state diagram:

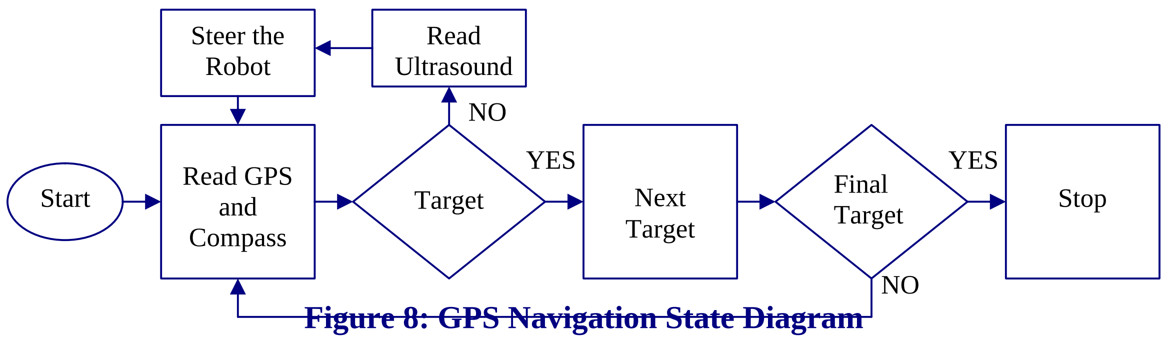


Figure 8: GPS Navigation State Diagram

The data acquisition and the motor steering processes are running simultaneously with the state machine process. This way, the decision making is continuously updated with newest data from the sensors and the motor controllers continuously receive new adjusted commands.

The path planning and reactive algorithms are both employed in the navigation system. 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. The reactive approach is used to avoid the obstacles. Once the obstacle is detected the path planning gets suspended and the ultrasound array is used to maneuver the vehicle around the obstacles in the shortest possible distance. When the obstacle is avoided the path-planning algorithm takes over again.

Even though the navigation algorithm involved many advanced programming techniques, the LabVIEW visual programming enabled the integration of these ideas into one reliable unity. The ability to visually inspect all the parts of the code, even while the program was running, contributed to the ease of implementing and debugging of the complex algorithms.

11. Performance Prediction and Analysis

Table 5: ***Table of Predicted and Tested Results of ALVIN-V Performance***

Performance Areas	Predicted Results	Tested Results
Robot Navigation	Capable of Completing Course in 9 min.	N/A
Battery Life	Motors: 1 h, Other Systems: 2 h	N/A
Speed	4.5 mph Maximum, 2 mph Typical	Actual Maximum 4 mph
Ramp Climbing Ability	15 degrees	15 degrees
Stopping Distance	2 ft	2 ft
Dead ends and traps	Robot Will Back Up Until Finding a Successful Path	N/A
Potholes	Accurately Detected and Avoided	N/A
Waypoint Accuracy	1 m	1 m

12. Safety Considerations

In the design of ALVIN-V safety was a primary concern. The robot, at 89 lbs, is easy to carry and transport. Two individuals can carry the robot at full load with the 20lbs payload. To ensure the safety of the robot and its operators, several safety measures were implemented.

The wire placements were planned and wired according to schematics. The schematics ensure that all the wires are correctly earthed and also that switches and controls are wired correctly. Fuses were placed to safeguard expensive electrical components, such as the LabVIEW Hardware and GPS receiver. Each switch has LED indicators to show they are engaged and powered. Extra wire lengths are tied down and clipped to the frame. The internal system is wired using 14-pin ribbon cable, for simple maintenance.

The robot body is made from lightweight molded polymer, so there is no chance of accidental electrical shock to the operators of the robot from the batteries. The battery housing has leads connecting to the robot and leads on the side of the robot, similar to electric car, allowing a charger to be plugged directly into the robot rather than having to remove the batteries for charging. The robot is ready to go at all times.

There are several methods of stopping ALVIN-V during a run. The first is a large red emergency stop button located at the rear of the robot, where an individual can easily access this button, causing the robot to come to a rolling stop within two feet. The second method is a remote emergency stop that can be used from a distance as far as 1000ft to make the robot come to a stop, also within a distance of two feet.

13. Cost Analysis

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

Table 6: ***Cost Breakdown***

Components	Retail Cost ($)	Cost Incurred ($)
Pyro IEEE Cameras(2)	180	180
Polaroid 6500 Ranging Modules(4)	184	184
Frame	40	40
Shell	20	20
Wheels	100	100
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
Ultralife 30V Lithium Ion Batteries (2)	770	0
Bosch 24V Nickel Cadmium Battery	186	0
Honeywell Compass (HMR-3300)	750	0
Ashtech BR2G-S (GPS Receiver)	3350	0
Total	20465	654

14. Sponsors

- Bosch Corporation
- Bayside Motion Group
- Bren-Tronics Inc.
- Connecticut NASA Space Grant Consortium
- Honeywell Inc.
- Intelligent Motion Systems Inc.
- National Instruments
- Thales Navigation
- Trinity College
- Travelers Insurance
- Teknicircuits Inc.
- Ultralife Batteries Inc.