

**FOURTEENTH ANNUAL  
INTERNATIONAL GROUND VEHICLE COMPETITION**

# ALVIN-VII

## Design Report

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Trinity College  
FUND. 1862



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## Faculty Statement

This is to certify that ALVIN-VII 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.

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## 1. Introduction

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

## 2. Improvements

ALVIN-VII boasts a variety of improvements over its predecessors in the areas of computer processing power, battery technology and mechanical reliability. By directing time and resources to deficiencies observed in last year's competition, the team has updated ALVIN to meet the demands of the Intelligent Ground Vehicle Competition (IGVC) and remain competitive.

A new, advanced chassis adds component modularity and features to the vehicle. Mechanical hardware has been standardized to simplify maintenance and the aluminum space frame skeleton ensures enhanced reliability during operation as well as collapsibility of the sensor array during transport.

Speed has been a main focus in terms of image processing and ground propulsion. The motors in the drive system have been replaced with a cutting-edge model that handles the torque requirements of mobile robotic applications. In addition to two onboard embedded processing units, ALVIN-VII features an additional National Instruments Compact Vision System (CVS) to more quickly process real-time line extraction algorithms and improve reaction time.

In order to reduce weight and meet the higher power requirements of the drive system, 30 Volt Lithium Ion batteries power ALVIN-VII's electronic systems and yet-to-be marketed 24 Volt NiMH batteries power from Nilar, Inc. power the motor system. These replace the much heavier lead acid batteries previously used, ALVIN-VII has now become a test-bed for these battery technologies in mobile robotic applications.

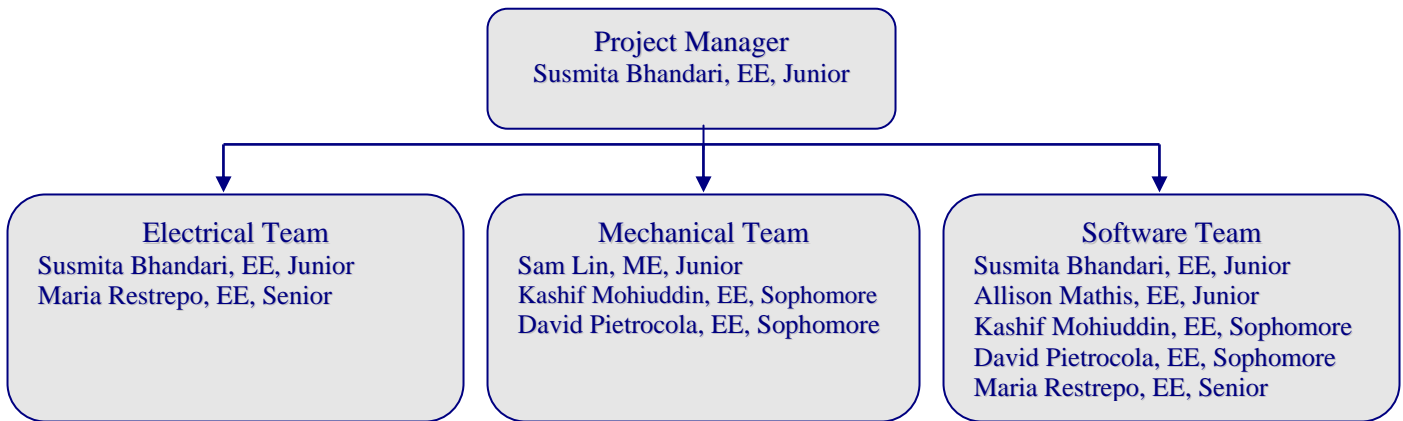
ALVIN-VII's design and architecture also incorporates partial compliance of the Joint Architecture for Unmanned Systems (JAUS). The standard is currently supported via an 802.11g interface that permits communication with other compliant systems. A modular architecture allows for messages to be effectively routed through the system, to different destinations including motor controller, sensor data acquisition or vehicle status query.

### 3. Design Process

With the need to improve and further develop the technologies aboard ALVIN while keeping in mind time and design constraints, the RST implemented a schedule and team structure to facilitate research and work throughout the academic year. A dedicated group consisting of RST members was charged with the task to prepare the vehicle for entry into the 2006 IGVC.

#### 3.1 Team Structure

The ALVIN team comprises students from many levels of undergraduate study and technical expertise. They represent different fields of engineering; namely, electrical and mechanical engineering. In order to effectively and concurrently make progress in the various onboard systems, the team was divided into three main functional groups, as shown in Figure 1.

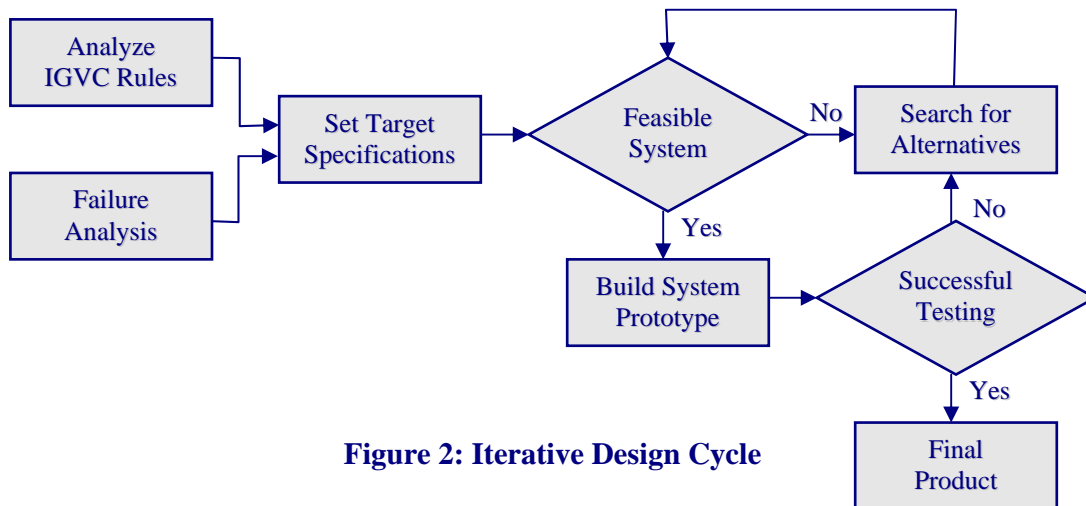


**Figure 1: Team Organization Chart**

As the overview shows, 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 1,200 person-hours were spent this year in the development of ALVIN-VII.

#### 3.2 Design Methodology

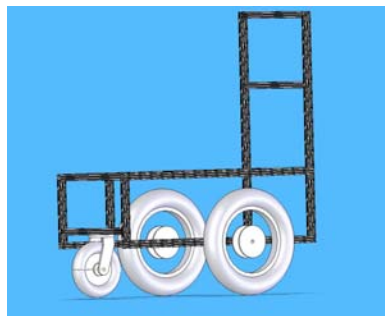
The engineering design process for ALVIN-VII begins with analysis of vehicle needs as determined by IGVC rules as well as an evaluation of previous performances. These requirements are integrated together with failure analysis and new innovations into target specifications for the new ALVIN vehicle. An iterative design process in which target specifications are continuously revisited and revised through the feasibility and production stages is fundamental to the team work strategy. This design cycle, along with feasibility testing, is illustrated in Figure 2.



**Figure 2: Iterative Design Cycle**

## 4. Mechanical Design

ALVIN’s chassis was rebuilt this year utilizing 80/20 extruded aluminum channel, which allowed for quick changes to component layout and easy optimization of weight balance and accessibility. The motors were upgraded and provide both simplified wiring and increased torque. The main goals targeted were weight distribution and increased mechanical reliability, as well as ease of use. A secondary goal was to make ALVIN-VII fit as small a footprint as possible in order to increase agility and ability to handle tight obstacle arrangements.



**Figure 3: Solidworks 3D model of ALVIN-VII frame**

### 4.1 System Layout

The driving factors behind the system layout and component placement were concentrating weight on the driven wheels to increase traction and decrease turning resistance from the third wheel (caster), minimizing wiring complexity and weight, and ensuring convenient access to all critical components. To achieve these goals, the motors are placed very close to the driven wheel axis and offset from each other to allow a narrower chassis. Remaining components are mounted low in the chassis to maintain a low center of gravity for maximum stability on inclines, and spread on both sides of the driven wheel axis, again to concentrate weight onto the driven wheels. Components requiring quick access like the power supply, power control and indicator panel, GPS readout, and

NI Compact Fieldpoint (cFP) unit are mounted near each other and concentrated at the rear of the vehicle, allowing access via a single access panel. Batteries are also placed near easily removable panels for quick replacement and minimal downtime. Again, the heavier Nilar battery was placed to concentrate weight on the driven wheels.

## **4.2 Drivetrain**

The drivetrain uses a pair of IMS MDrive Plus MDM34AC prototype brushless stepper motors, attached to Parker-Bayside NEMA34 10:1 gearheads. This along with a belt drive ratio of 16:9 translates to an effective gear ratio of 160:9. The motors incorporate integral programmable microstepping controllers, reducing wiring complexity and increasing durability, and use lightweight alloy cases that result in a net weight savings over a conventional stepper motor and external controller combination. The motors allow high flexibility in power supply choice, as they can be run on AC or DC power from 95 to 132 VAC. The gearheads drive Browning cogs using a taper shaft lock which allows easy changing of belt gear ratios, while remaining secure and reliable. The choice of a belt drive system allows the belt to act as a damper and isolate the motors from large transient shock loads. Belt tension is quickly set due to the easily adjustable nature of the 80/20 extrusion, and belt life is high due to the choice of urethane belts with Kevlar fiber reinforcements. The wheels roll on high-quality Phil Wood racing wheelchair hubs, designed for extreme durability and low friction in high shock abusive environments.

## **4.3 Mobility**

The use of large 18” diameter driven wheels and a 8” diameter caster allows ALVIN-VII the ability to easily navigate rough terrain and traverse objects up to 4” in height. The tripod wheel arrangement is naturally stable and retains all points of contact in any terrain. The wheels are the widest point of the robot and give a broad stance that provides stability past a 40° lateral incline in testing. The opposed drive wheels are independently driven and allow axis turns to be easily accomplished at any time. ALVIN-VII’s length is the minimum allowed by regulations and width is half of length, giving it the ability to easily navigate through small passages between obstacles.

## **4.4 Reliability**

The 80/20 extrusion forming ALVIN-VII’s backbone is designed for industrial environments and is resistant to dirt, moisture and vibration. The extrusion’s profile is tapered to allow all hardware attached to it to be self-locking, simplifying the choice of hardware and further reducing weight. All critical electrical connections utilize positive locking connectors that are immune to

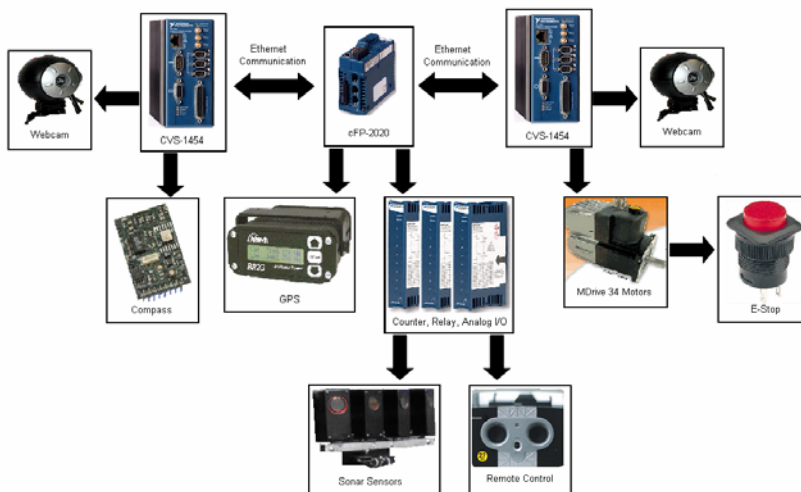
shock and vibration and provide tactile feedback to confirm proper connection. Wiring is carefully dressed with strain reliefs to prevent fatigue failure. The motors utilize MIL plugs and are IP65 weather sealed. All components are mounted using multiple points and protected by durable acrylic panels that are resistant to the environment and impact for all-weather operability. The wheels and caster are loaded at a fraction of their rated design loads, giving a large margin of safety.

## 5. Electrical System

The onboard electronics and power distribution system have been dramatically improved in ALVIN-VII to ensure reliability and robustness during operation. Custom power distribution circuitry with extensive safety features supplies three voltage levels from one battery source to accommodate the various power requirements of the electronics. A separate, isolated power source supplies 120 VAC via an inverter to the drive system. Safety and reliability have been fundamental concerns throughout the ALVIN development process.

### 5.1 System Integration

Components are connected to one of three embedded National Instruments processors that control the various tasks during operation and communicate in a real-time environment via Ethernet. The modular architecture facilitates ease of maintenance and accessibility in software and permits parallel processing and data analysis across all controllers.



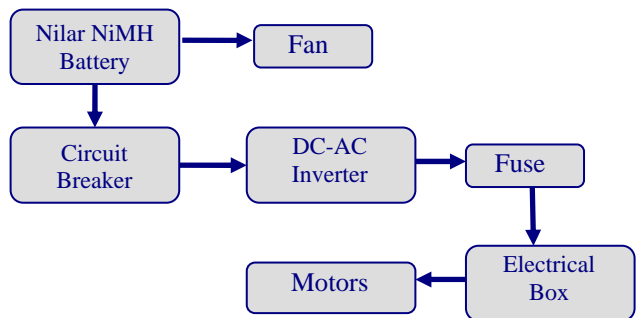
**Figure 4: Overview of System Integration for ALVIN-VII**

### 5.2 Power Supply

ALVIN-VII's power supply comes from two different battery sources. The two brushless stepper motors are powered using a Nilar nickel metal hydride (NiMH) 24 VDC 10AH membrane

battery. This battery has a relatively horizontal discharge curve that enables it to provide a steady power over a range of voltages. It is highly compact and lightweight with dimensions of 278 x 129 x 57 mm and weight of 4.3 kg. Its features such as deep cycle capacity and high energy density together with its robustness makes this battery ideal for powering motors.

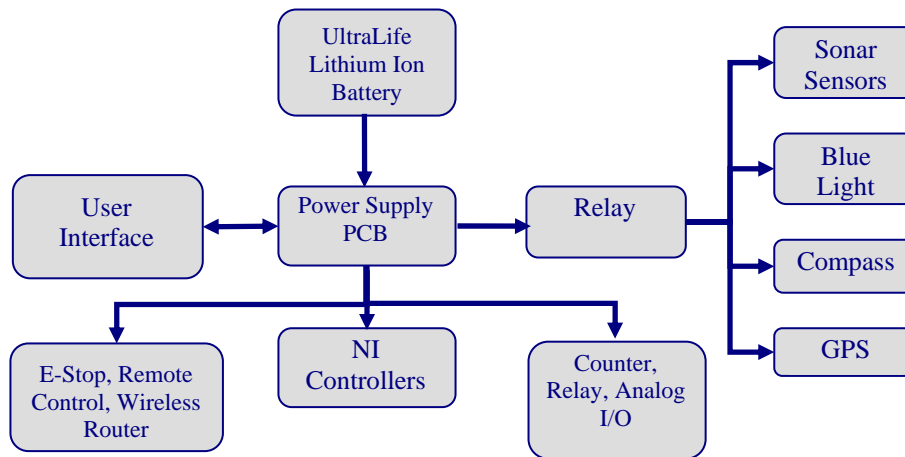
The Nilar battery is used in conjunction with a 1400 Watt DC to AC power inverter to supply a clean steady source of power to the stepper motors. In order to ensure more safety an electrical box is placed between the motors and the output of the inverter. This electrical box shown in Figure 5 consists of a 15A fuse and two standard three pin outlets that interface with the standard Euro AC connector of the motors.



**Figure 5: Power system and safety features for onboard motors.**

All other electronic components are powered using an UltraLife Lithium Ion battery. The battery provides 6 AH continuous at 30 VDC, resulting in a run time of approximately one hour. It is extremely lightweight and compact, weighing in at 1,440 grams. Unlike most batteries, in addition to being lightweight, it has a high energy density providing a total of 173 WH of continuous power.

The power from the UltraLife battery is converted to +5, +12, and +24 Volt regulated potentials by DC-to-DC converters that are mounted on a custom printed circuit board. The board accepts input voltages in the range of 18-21 VDC. For safety, several circuit breakers and heat sinks are put in place to limit the current and dissipate heat respectively. A regulated clean supply of voltage is extremely important for onboard equipment, and bypass capacitors between each voltage line and ground achieve this purpose. Figure 6 illustrates the power distribution of onboard components and shows points of LabVIEW-controlled relays.



**Figure 6: Power distribution for electronic components**

### 5.3 User Interface

User initialization of ALVIN-VII occurs via the user control panel that is located in the rear of the vehicle. The control panel features an on-off switch for the main system along with a switch to select either navigation or autonomous challenge mode. The panel also features an analog display for the current voltage level of the system battery as well as the 5 V, 12 V, and 24 V lines on the power supply. ALVIN-VII can also be operated using a remote control that directly controls the motors and the E-Stop as a safety precaution. The onboard 802.11g wireless router allows remote programming and data logging. This feature proved to be invaluable during testing, as it allowed us to monitor ALVIN-VII’s progress closely.

### 5.4 Safety

The safety concerns have been given the utmost priority in ALVIN-VII. 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 for each voltage line. In addition, the rear control panel serves as a safe interface to operate the vehicle.

The presence of 120 VAC and the extremely high current draw throughout the motor power system necessitates proper handling and care to ensure safety of the vehicle and team members during operation. The Nilar battery is equipped with a nylon-insulated, AWG 6 copper wire and quick connectors, rated at 50 Amperes, for easy and efficient connections to the vehicle’s onboard circuitry. An industrial grade 40 A circuit breaker interfaces the battery and 1400 Watt inverter for additional component safety. The motors’ Euro cables are fitted with industrial grade three-prong connectors, which feed into an isolated electrical box that includes a 15 A inline power fuse and

LabVIEW-controllable solid-state relay. This is to maintain the safety of the inverter, which has a 20 A fuse rating. All cables on the AC side of the inverter are high-quality AC wires rated for 15 A.

The stopping of the vehicle is another safety consideration. ALVIN-VII can be stopped in three ways, each of which can bring the robot to a complete stop within a distance of two feet. One way is to use the red e-stop push button on the top rear end of the vehicle. Another method is to use the remote control to wirelessly stop the vehicle 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 inverter. All three methods are safe and accessible for use.

## **6. Sensors**

The advancement of commercially available sensor systems has made intelligent and efficient obstacle avoidance a simplified process in mobile robotics. ALVIN-VII utilizes four sonar sensors, two digital cameras, a compass and a differential GPS to perceive its environment and support intelligent operation. All sensors are connected to the three onboard NI processors.

### **6.1 Digital Cameras**

ALVIN-VII uses two ADS Tech Pyro cameras for its vision system. Both cameras use a 640 by 480 pixel resolution with an update rate of 15 frames per second (fps) and are interfaced to separate CVS modules through IEEE 1394 ports. The cameras are mounted with custom built devices that allow for 90° of freedom in both the vertical and horizontal direction.

### **6.2 Sonar Sensors**

Obstacle avoidance is carried out by a bank of four sonar sensors that are interfaced with NI counter modules (cFP CTR-500). Each SensComp/Polaroid 6500 ranging module is capable of detecting objects between 6 inches and 35 feet to an accuracy of 1%. While the operating voltage for the sonar modules is 5 V, the counter module does not respond to signals below 12 V, so some signal manipulation is required to interface the two modules. The sensors are contained in custom built housings that are mounted using an adjustable but stable frame. For calibrating the sonars an object is placed in between two adjacent sensors and the positioning of the inner one is adjusted until the object is just in its range of vision to ensure minimum overlap between the two sensors. This process is carried out for all the sonar sensors.

### **6.3 Digital Compass**

Vehicle orientation on ALVIN-VII is obtained using a Honeywell HMR-3300 digital compass that is interfaced with a CVS module through a standard serial port. The compass provides precise readings for the azimuth angle and has a range of  $\pm 60^\circ$  for pitch and roll data with an accuracy of  $\pm 1^\circ$ .

### **6.4 Differential Global Positioning System (DGPS)**

Vehicle localization is achieved by means of an Ashtech BR2G-S GPS receiver. The receiver combines dual channel beacon receiver technology with industry standard Ashtech 12-channel precision GPS for reliable readings. The receiver is interfaced with the NI cFP module through a standard serial port. The antenna for the GPS is mounted on top of the sensor tower to ensure reliable readings.

## **7. Software**

All software development and programming is achieved through the National Instruments Real-Time LabVIEW environment. The language's modularity along with the ability to perform multiple and distributed parallel tasks across ALVIN-VII's three processors in real time is central to the robot's intelligence capabilities.

### **7.1 Computer**

The NI Compact Fieldpoint is the main controller during operation. Two NI Compact Vision Systems feature Intel Celeron 400 MHz processors along with convenient FPGAs. All three processors are connected to a Belkin Wireless G Router and interfaced via 100 Mbps Ethernet.

### **7.2 Software Operation**

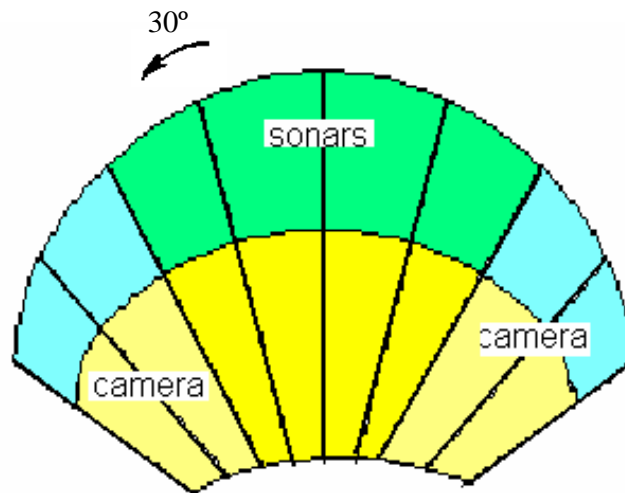
ALVIN-VII's programs start when the operator turns on the main system switch on the user interface panel. This powers all the electronic components onboard that are not controlled by the relay module. The robot runs in three different modes: autonomous, navigation and standby. Two other switches on the back panel provide a convenient way of changing between modes. The operating code is distributed across three processors which communicate via Ethernet communication. The image processing code is loaded into the left and right compact vision systems and the motor control into the left CVS. The cFP handles the main autonomous and navigation codes, whereby data collected from counter and analog I/O modules are integrated together with those from serial ports of both the FieldPoint and the vision system. The stand by operation is used

first to establish a communication protocol among the three processors. Once they have successfully communicated, a group of four LEDs in the fieldpoint light up in sequence indicating that the robot is in stand by mode and is ready for autonomous or navigation operations. While in this mode, radio frequency communication can be established between a remote control and the vehicle. By switching from stand by to start and choosing autonomous or navigation in the back panel, the vehicle's mode of operation can be initiated.

### 7.3 Obstacle Avoidance

Obstacle avoidance is performed using the sonar sensor array along with the cameras for line and pothole detection. A virtual polar grid representing the area in front of the robot includes a total of eight regions, with two threshold zones mapped for each at 3 meters and 5 meters. The sonar array covers obstacle detection in the middle four regions while the cameras flank the left and right sides. If sonar sensors detect an obstacle, the obstacle's region and zone are determined and they are subsequently marked as dangerous territory.

Line detection and pothole data is integrated via a user-defined coordinate system across the grid. The endpoints of lines are retrieved via line extraction and the regions in which the line crosses are determined. After identifying what grid regions are occupied, a unique state number is assigned to represent the obstacle arrangement in front of the robot. This is run through a comprehensive lookup table that 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 7: Obstacle detection integration grid**

### 7.4 Real-time Line Extraction

Lines are extracted from the images captured by two Firewire digital web cameras in a real-time environment. The raw images are passed to two NI CVS controllers where parallel processing is performed to extract the lines, detect potholes and recognize the presence of a ramp.

The image processing algorithm was developed using National Instruments IMAQ Vision Builder and utilizes hue, saturation, and luminance of an input image. In addition, the image is sent through a number of low pass and particle filters to reliably extract lines and potholes. The thresholds for filtering are determined through statistical analysis, which makes the algorithm effective in a variety of outdoor lighting conditions. The ramp is recognized by its specific smooth texture.

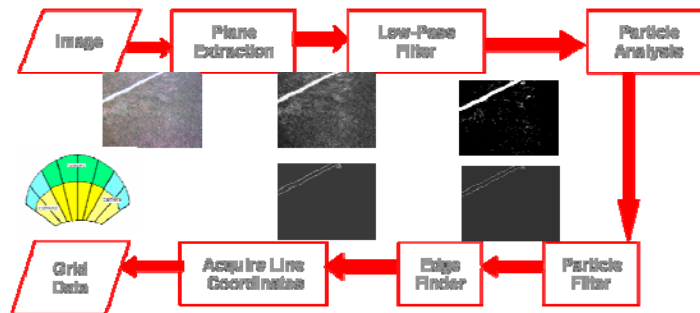


Figure 8: Line extraction algorithm

### 7.5 Autonomous Challenge Algorithm

The autonomous challenge algorithm is based on the state machine algorithm shown in Figure 8.

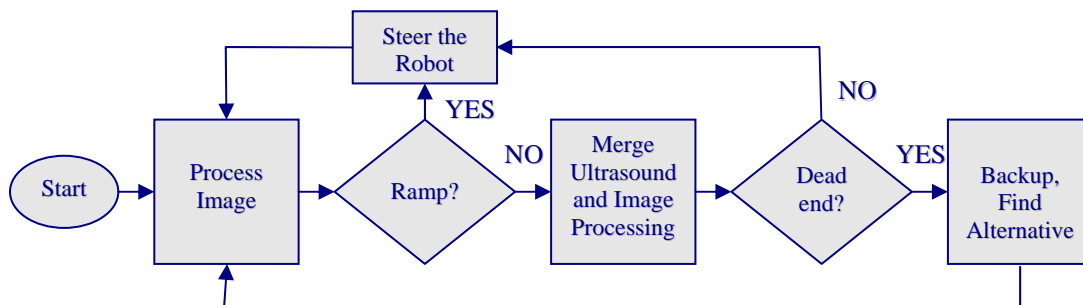
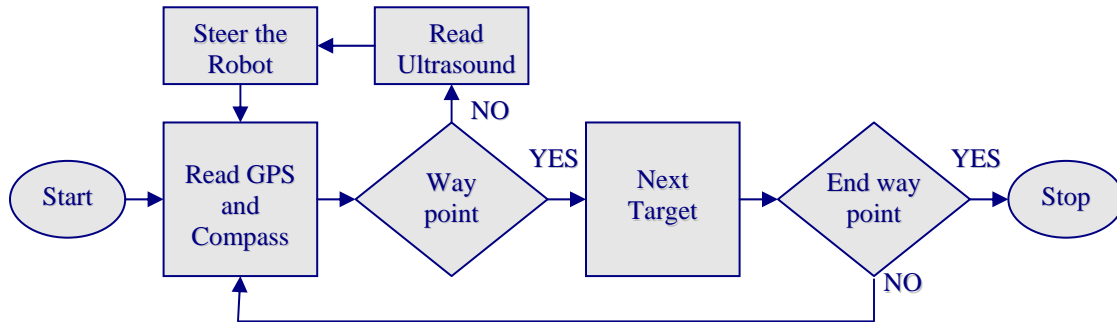


Figure 9: Autonomous Navigation State Diagram

All the data acquisition from the cameras, sonars and compass along with the motor steering process are done in parallel with the state machine algorithm to ensure that all decision-making is based on continuously updated information. Using the obstacle avoidance algorithm, the safest path is determined. In order to prevent backtracking, a limited history of compass data is saved in memory to maintain a constant forward direction reference vector.

## 7.6 Navigation Challenge Algorithm

The GPS navigation algorithm operates in a manner similar to that of the autonomous code. It is a state machine that takes the data from the sensors and uses it to determine when, and how sharply it must turn. This information, used in conjunction with the data from the GPS receiver, makes up the base of the algorithm detailed in Figure 10.



**Figure 10: GPS Navigation State Diagram**

The navigation system uses a combination of reactive and path planning algorithms. Unless the sensors locate an obstacle within a dangerous range, a direct line is plotted and followed from the robot's current position to that of the next waypoint. However, should an obstacle be detected, the system will switch to a reactive response in which it traverses around the obstacle as quickly as possible using the ultrasound sensors, and will then return to path planning using the GPS.

## 7.7 JAUS Implementation

In light of the rising importance of the Department of Defense's Joint Architecture for Unmanned Systems in the field of autonomous robotics and the 2006 IGVC voluntary JAUS compliance test, additions and modifications have been made to the hardware and software of ALVIN-VII. This is a first step toward making the ALVIN platform completely JAUS compliant by 2007.

The relatively recent publication of the open standard made it difficult for team members to evaluate existing implementations. A majority of the fall semester was spent reading and understanding the concepts and technical aspects of the three-part version 3.2 reference architecture. This reading was supplemented by reviewing master theses in the fields of autonomous robotics and JAUS from engineering graduate schools at the University of Florida and Virginia Polytechnic Institute and State University.

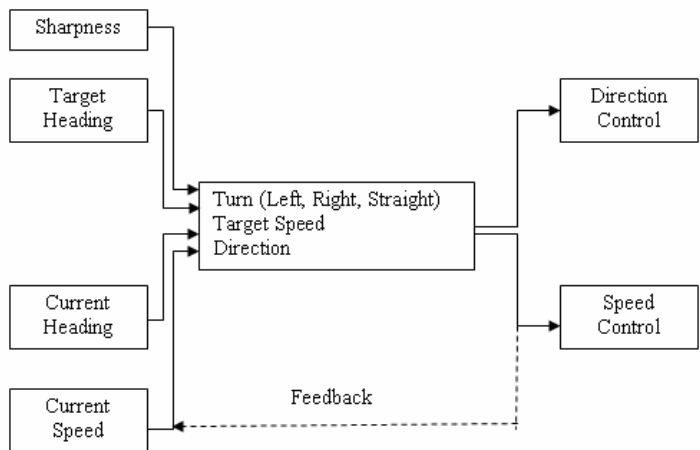
The JAUS compliance level necessary for the voluntary test was implemented in two stages. During the initial design process for ALVIN-VII, an IEEE 802.11g wireless router was researched to

ensure compatibility with the onboard power distribution system and ongoing research for new motors included careful attention to controller modularity in anticipation of a fully JAUS-compliant system. Once the Interface Control Document was released to IGVC teams, a LabVIEW 8.0 sub-VI was created to communicate with the robot’s wireless gateway and intercept incoming JAUS messages within the UDP packets on port 3794. Depending on the decoded command message, instructions are sent to the respective areas in the ALVIN software to successfully carry out the defined task.

A variety of challenges were encountered during work toward partial JAUS compliance. By introducing a router to ALVIN-VII’s tri-processor architecture, programming and software maintenance procedures were modified to bypass the system’s single gateway entry point and keep processor targets directly accessible in LabVIEW. Other obstacles included deciphering UDP packets and decomposing the many parts of the JAUS message.

### 7.8 Motor Control

The software program for motor control is greatly simplified by the integrated microstepping driver in the brushless stepper motors. Using the known current speed, current compass heading, target heading and the sharpness of the turn, the algorithm determines the direction and speed with which it needs to turn. The speed control that determines the frequency at which the motors need to run is obtained from a pulse generator programmed in the Field Programmable Gate Array (FPGA) device aboard a CVS. With accurate LabVIEW control and precise motor movement, the motion of the vehicle is consistently smooth and reliable.



**Figure 11: Motor Control Diagram**

## 8. Predicted Results and Testing

Individual system performances as well as overall vehicle operations have been evaluated through a variety of lab experiments and real world testing applications.

### 8.1 Speed

ALVIN-VII incorporates a 10:1 gearhead and belt drive system whose cogs are geared 16:9, for a 2-stage speed reduction. The 18” diameter drive wheels and a theoretical maximum value of 3,000 rpm for the motors, corresponds to a theoretical maximum speed of 14.4 mph on level surfaces. However, in compliance with IGVC speed regulations, the integrated motor controller is configured to limit speeds to 5 mph.

### 8.2 Ramp Performance

ALVIN-VII’s sensor network has no problem handling inclines, and with most of the weight concentrated on the driven wheels, traction is not a concern ascending or descending the ramp. Extensive testing has shown the robot to be stable in all directions to over double the contest-specified ramp incline of 15% grade. The motors have high holding torque and controllability at low speeds, allowing ALVIN-VII to easily navigate the ramp in all circumstances.

### 8.3 Battery Life and Power Consumption

With one lightweight Ultralife battery running aboard the vehicle during operation, the system is capable of 70 minutes of continuous runtime before the battery must be replaced. Likewise, with one Nilar NiMH battery attached to the AC inverter, the motors have been tested to run for approximately 30 minutes in real-world conditions.

**Table 1: Power Consumption on ALVIN-VII**

<b>COMPONENT</b>	<b>CURRENT (Amps)</b>	<b>VOLTAGE (Volts)</b>	<b>POWER (Watts)</b>
IMS MDrive 34AC Motors	3 x 2	120 VAC	510*
PowerBright 1400 Watt Inverter	1	24	24
(2) NI CVS-1454 Vision Systems with (2) ADS Tech Pyro Cameras	4	24	100
NI cFP-2020 Controller With Two NI Modules (counter and relay)	1	24	24
Belkin Wireless G Router	1.5	5	7.5
Ashtech BR2G-S GPS Receiver	0.5	12	6
Honeywell HMR-3300 Compass	0.02	12	0.24
(4) Polaroid 6500 Ranging Modules	0.5	5	2.5
Remote Control and Emergency Stop	0.5	5	2.5
*Note: Value is for maximum speed at maximum load.			
Total Power Consumption			657 Watts

## 8.4 Dead Ends, Traps, and Potholes

Situations involving dead ends or traps are integrated into ALVIN-VII's path planning algorithm. If an adequate path cannot be found, the robot backs up until it is successful. In the autonomous challenge, the limited stored history of compass data prevents the vehicle from navigating in the wrong direction. Furthermore, pothole detection is integrated into the main image processing algorithm and is treated as an obstacle in ALVIN-VII's mapping grid. In testing, dead ends have been unable to hamper the vehicle's progress while potholes have been successfully detected and avoided.

## 8.5 Reaction Time

In navigation challenge mode, the decisions are made in real-time as the obstacle arrangement grid is updated every 220 ms. At 5 mph, ALVIN-VII has a stopping distance of 0.5 meters thanks to the precision and high torque of the stepper motors. In autonomous challenge mode, raw images captured from the digital cameras are processed in parallel four times a second, with each instance of the line extraction algorithm taking 55 ms. This translates to a new command with updated parameters being sent to the motors every 0.2 meters of ground travel.

## 8.6 GPS Waypoint Accuracy

The DGPS receiver is accurate to within 1 meter of a waypoint and is unaffected by cloudy or overcast weather conditions. In testing, ALVIN-VII reached a variety of waypoints within an accuracy of 1 meter or less.

## 9. Cost Analysis

Throughout the design and fabrication process of ALVIN – VII a concerted effort was placed on minimizing the cost by actively pursuing industry donations and supports. This effort was very successful in reducing the costs incurred by the team. The table below shows the different components used in ALVIN along with their retail cost and cost to the team.

<b>COMPONENTS</b>	<b>RETAIL COST (\$)</b>	<b>COST INCURRED (\$)</b>
ADS Tech Pyro Cameras(2)	180	180
Polaroid 6500 Ranging Modules(4)	180	180
Frame	350	350
Aluminum Sheet	50	50
Wheel Chair Wheels w/ Phil Wood Racing Hubs	350	350
Wiring	50	50

Gears and Belts	250	80
IMS MDrive34AC Plus Motors (2)	1500	0
Belkin 802.11g Wireless Router	50	50
NI LabVIEW Developer Suite	4295	0
NI LabVIEW IEEE Drivers	990	0
NI LabVIEW Vision Dev. Module	2595	0
NI CVS-1454 Vision System (2)	5990	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 Battery	385	0
Nilar Membrane NiMH 24V 9Ah Battery	225	0
Power Bright 1400 Watt Invertor	190	0
Honeywell Compass (HMR-3300)	750	0
Ashtech BR2G-S (GPS Receiver)	3350	0
Remote Control	50	50
Power Supply Board	150	0
Total	24805	1340

## 10. Conclusion

ALVIN-VII is a completely autonomous vehicle designed by the Robotics Study Team (RST) at Trinity College. The vehicle features an adjustable modular lightweight aluminum frame that enhances its ability to traverse rough terrain and ascend steep inclines. The use of integrated stepper motors along with two Firewire cameras and a bank of sonar sensors greatly simplified the design process, allowing three onboard processors to process all sensor data and control the motors simultaneously. By the process of iterative design along with the help of latest software tools and cutting edge battery and motor technology, the RST has developed ALVIN-VII, which is an example of a robust and efficient autonomous vehicle that should perform well in all three events in the 14<sup>th</sup> annual IGVC competition.

## 11. Sponsors

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