ELEVENTH ANNUAL
INTELLIGENT GROUND VEHICLE COMPETITION

ALVIN IV

Design Report

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STATEMENT FROM FACULTY

This is to certify that ALVIN IV 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,
Professor of Engineering, Trinity College

Section I: Introduction

This report presents the redesign and reconstruction of a fourth generation unmanned ground vehicle ALVIN-IV at Trinity College. After a careful design study and performance evaluations of the previous year's performance, the team developed a lightweight, intelligent, safe and technically superior robot in the form of ALVIN-IV. The software system from the previous years was replaced with a new approach using National Instruments LabVIEW. The navigation algorithm used in previous years has been replaced allowing ALVIN IV to perform well in both the navigation challenge and the autonomous vehicle challenge. The robot superstructure has been replaced with a custom built cover using lightweight plastic. ALVIN IV has superior computing capabilities than previous generations and is equipped with dual Firewire cameras as well as ultrasonic sensor array.

Section II: Team Organization and Design Procedure

2.1 Team Organization

Five members of the Trinity College Robot Study Team were assigned to the ALVIN Redesign Project with valuable research and suggestion provided by the entire Robot Study Team. Table 1 shows the names, class level and responsibilities of each member of the ALVIN Sub-Team.

Name	**Class**	**Responsibility**
Nhon Trinh	Junior	Chief Engineer, Vision System, Sensor system
Trishan de Lanerolle	Junior	Project Leader, Navigation System, CAD
Michelle Bovard	Junior	Mechanical Design, CAD, Navigation System
Matthew Gillette	Sophomore	Vision System, Drive System, Electrical Systems
Bozidar Marinkovic	Sophomore	Navigation System, Simulator

Table 1: ALVIN Team Members and Responsibilities

The team members met every Tuesday afternoons as a sub-team and every Thursday afternoons with the rest of the Robot Study Team to report progress and generate ideas.

2.2 Redesign Process

Since ALVIN-IV was a re-design vehicle the first thing that was necessary was to identify the need for a design change. Vehicle performance and personal experiences at the 2000, 2001 and 2002 IGVC competitions together with communications with a few other IGVC teams formed a major guideline for the design changes. The performance at the 2002 competition was broken down into several sub systems mainly GPS system, drive system, vision system, algorithm analysis and Systems Integration , critical elements identified by the team and a critical path was written.

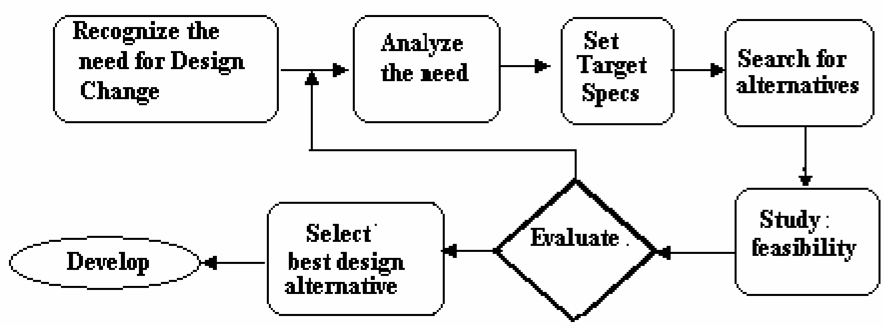

Figure 1: Redesign cycle for ALVIN-III

The main areas identified were the lack of bearing information to work out the correct direction to move in. ALVIN III used a mathematically intensive algorithm to calculate these values and wasn't accurate. Alvin IV is equipped with a digital compass to give accurate bearing information and figure out the direction the robot is pointing. The previous drive system was found to be more than adequate for the robot and has not been changed. There were two noticeable problems: the drive train did appear to slip slightly and there were problems when traveling over the ramp at an angle. The gear belts have been tighten and new control software for the drive system has been written to give greater control over the motors. ALVIN entered IGVC 2002 with heavy expectations for the vision system. The system largely failed on the day of the competition. This caused a complete rethinking of the strategy used in obstacle and lane detection. Varying light conditions and shadows caused the image processing algorithm to perform unreliably. For the 2003 competition the robot uses a new approach to lane and obstacle detection.

Major changes have been made to the sensory hardware and the software used on the robot to take into account additional sensors and more information from color images. For the 2002 competition the robot sported a new electric system, with a new laptop. For the 2003 competition the laptop has been replaced with a more powerful model equipped with IEEE 1394 ports for new dual color cameras. ALVIN IV will use new navigation algorithms developed with National Instruments LabVIEW 6.1. LabVIEW 6.1 was chosen because it provides rapid prototyping capabilities, built-in advanced vision processing algorithms, the ability to easily handle multiple types of input, and the ability to implement a state machine.

After taking the previous years performance into account the following design changes were deemed necessary:

- The weight of the vehicle must be minimized.
- The Drive System must be easy to control and highly maneuverable.
- The camera system must be able to adapt to the variation in the lighting conditions and shadows during a run.
- The camera system must be able to auto-calibrate.
- The remote E-stop device must not be triggered by other wireless sources operating at the same frequency.
- The casing on the robot must be made of light material and should be water tight enabling the robot to be run in wet weather.
- The speed control unit and the navigation software must be changed to detect motor torque out and to pass over speeds that cause a high motor resonance.
- New sensors need to be integrated for secondary object detection as a failsafe.
- A need was found for a method to track the robots movements, to know what direction it was going in, if it were back tracking on its self and attempt to correct the error.

2.3 Target Specifications

With the major design changes identified, a target specification for the vehicle was developed. The rules of the IGVC and the design changes deemed necessary formed a basis for the target specification. The initial target specifications were carefully considered with alternative implementations considered for each specification generated.

After careful feasibility study that considered factors such as design time, design feasibility and cost the following specifications were drawn and the following materials selected. Below is a summery of ALVIN IV features.

Weight: 99lbs including 20lb Payload
Dimensions: 3ft x 1.5ft x 2 ft

Vehicle Frame and Cover:
Frame: light weight aluminum tube.
Cover: Light weight molded Plastic.

Sensory System:
Camera: Two Pyro IEEE 1394 webcams.
Vision Software: National Instruments LabVIEW 6.1
GPS: Ashtech BR2G-S GPS receiver
Ultrasonic Sensors: Four Polaroid 1600 ranging modules

Drive System:
Motors: M2-3424 Stepper Motors
Motor Controller: IM1007 Microstepping Controllers
Gearbox: NE34-01 10:1 Gearbox
Wheels: Bicycle Wheels in front and Pneumatic Caster on the back

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

The use of SOLIDWORKS 2003, a 3D modeling package, was made for mechanical design changes. The CAD tool was used for object packaging, weight distribution in the vehicle, stress point analysis and for the calculation of the center of gravity of the vehicle. The CAD tool also enabled the team in understanding the impact of mechanical changes and its usefulness before having to do it in hardware.

Section III: Electrical System

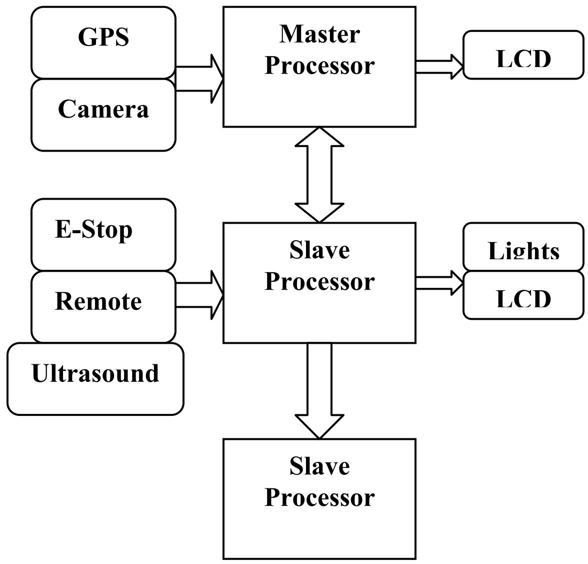

Figure 2: The overall Electrical System Block Diagram

The vehicle retained the master-slave concept used in 2002 IGVC competition. However the code in both the slave and master have been rewritten to give greater low level control and take into consideration new input information. A Sager 2.4 Ghz Pentium IV processor laptop running Windows XP makes the master processor for the system. The master processor receives its main input from the two Pyro IEEE 1394 cameras, performing real time analysis on the images at 10 frames/sec(fps) using LabVIEW's image processing capabilities, and processors the ultrasonic sensor array readings requested from the Slave processor. It also receives Differential GPS data during the navigation challenge through the serial port. Based on the image and GPS data processing results, the navigational decisions made by the master processor are passed onto the slave via RS232 communication link. A VESTA SB2000-332 board running a VESTA BASIC operating system acts as a slave processor. This processor receives data from the remote E-Stop on a TPU (Timer Processing Unit) channel, the mechanical E-Stop, the ultrasonic readings on TPU lines and a control signal from the master processor. . Based on the decision made by the master, the slave then sends out appropriate control signals to the motor controllers, the LCD display and the strobe lights. The master processor features Wireless Ethernet card and runs WINVNC virtual neighborhood software for easy debugging purposes. The master processor is operated with a built-in hot swappable rechargeable battery system while the slave uses a 9.6V NiCd battery pack. The normal operating life of the batteries with full electrical load is 1hr.

Section IV: Drive System

The drive system on ALVIN consists of a pair of 16 inch bicycle tires, a pair of IM1007 micro stepping drives together with the IM3424 34 frame high torque stepper motors and a light weight 10:1 gearbox system. Table 2 shows the specifications of the drive system and Fig. 3 shows the operating torque curve at the wheels of the robot. The control software has been rewritten to give greater control over the motors; the master system can send motor stepping speeds directly to the vesta control.

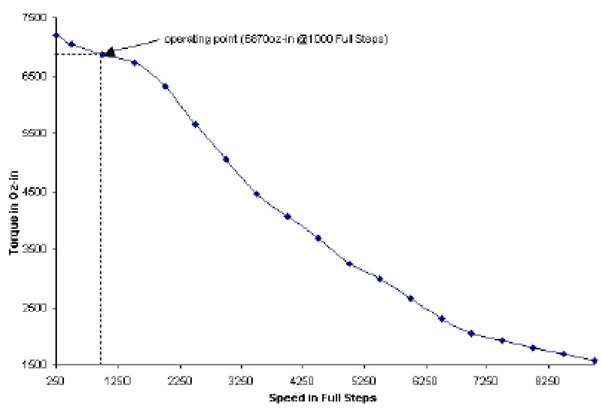

Figure 3 Torque curve at the wheels of ALVIN @ 7Amps and 60V

	Drive System
Overall Gear Ratio	18.9:1
Operating Voltage	60V
Operating Current	7.0A
Operating Full Step	1000
Overall weight	12 lbs
Operating Torque at wheels	6870 oz-in

Table 2: Specifications of Drive System

Section V: Sensory System

The sensory system on ALVIN-IV consists of the vision system, ultrasonic sensor array and DGPS navigation system. The vision system is the sole sensor system used for lane following and the ultrasonic sensors are used for obstacle avoidance. The data from the various sensory systems are used in conjunction to formulate a path for the robot to follow.

5.1 Vision System

The previous single USB web cam was replaced with two faster IEEE 1394 Pyro web cams. The cameras feature an automatic gain control, which helps the navigation system adapt very easily to the changing lighting conditions during an individual run. The color images are acquired at 640x480 resolutions at 15 fps. The cameras are 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.

5.2 Ultrasonic Sensor System

ALVIN IV will have an ultrasonic sensor Array mounted in the front of the robot scanning an area of 120 degrees. The array consists of four Polaroid 1600 ranging modules in custom-built housing.

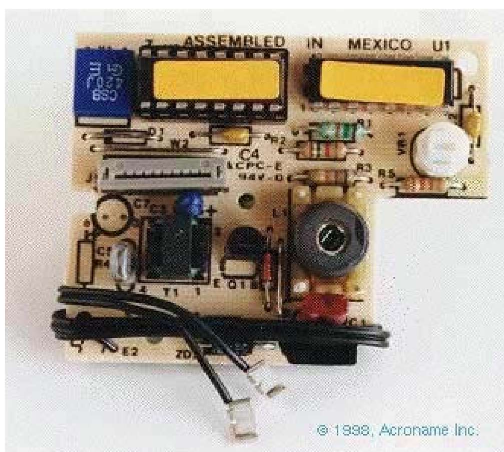

Figure 4: Polaroid 1600 Ranging module

The 6500 Series is an economical sonar ranging module that can drive all Polaroid electrostatic transducers with no additional interface. This module is able to measure distances from 6 inches to 35 feet. The typical absolute accuracy is (+-) 1% of the reading over the entire range. The module is able to differentiate echoes from objects that are only three inches apart. The digitally controlled-gain, variable-bandwidth amplifier minimizes noise and side-lobe detection in sonar applications. The module has an accurate ceramic-resonator-controlled 420-kHz time-base generator. An output based on the 420-kilohertz time base is provided for external use. The sonar transmit output is 16 cycles at a frequency of 49.4 kilohertz. The 6500 Series module operates over a supply range of 4.5 volts to 6.8 volts and is characterized for operation from 0° C to 40° C.

5.3 GPS Navigation System

ALVIN IV 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. The DGPS readings give the robots current position. Digital compass readings are used to calculate the robots bearing. The GPS and compass readings are used in conjunction with data from the ultrasonic sensor feedback to formulate the closest path to the target and move towards it. This is carried out using the new dynamic window algorithm.

Section VI: Mechanical Design

The frame designed using 6061-T6 Aluminum extruded square tubing was retained because of its light weight, strength, stability and ease to work with. The external cover has been redesigned and is currently being completed. To design a new outer cover for ALVIN, the entire robot was modeled in Solidworks, and then a new cover was designed entirely in Solidworks. The new outer cover is made of weather proof plastic material molded to specifications designed using the Solid works 2003 CAD application. The material is durable and lightweight and easy to assemble and disassemble. The body for ALVIN IV was fabricated by Industrial Safety limited in Hartford Connecticut using the cad drawings designed by ALVIN team members.

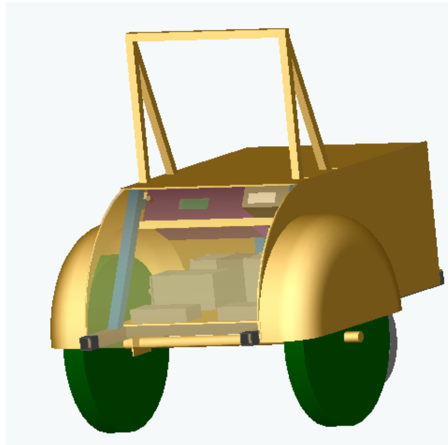

Figure 5: 3D rendering of ALVIN IV

The body was designed to be durable, lightwieght, and waterproof, and also to provide easy access to all the electronic parts of the robot. The side panels are fastened to the frame and need only be removed in the unlikely event of motor failure. The top, front and rear panels are movable to gain access to the critical electronic components and control switches as well as to replace the batteries. These areas are also clear to provide visibility to the controls and displays while the robot is moving.

Section VIII: Software and Control Strategy

The control strategy used in IGVC 2002 was found to be inadequate and failed to perform to expectations. For the 2003 competition the control of the drive system has been redesigned as well as the data acquisition software on the slave system. The path planning software uses a new approach and a new strategy was formulated after researching various alternatives.

The drive system was previously controlled with single character inputs. This was found to be too simplistic and a new more complex communication protocol was written. This protocol was written to include communication with the new ultrasonic sensor array and compass data. The new communication system allows the master system to send more information to the slave system such as request for particular input data and control the motor with greater certainty. The new communication protocols have the added advantage of being easy to trouble shoot and expand to include more inputs and outputs.

8.1 Path Planning

ALVIN IV uses an algorithm based on potential fields to finding the best path to move along. The master system takes in data from the two cameras to aquire the position of the lanes on either side of the robot. The ultrasonic data gives the exact position and size of obstacles in front of the robot. The sensors are read sequentially from left to right every second to build a output similar to a radar sweep. These data items are then merged together to form a map of the environment around the robot of approximately 270 degrees from the left to right side of the robot with in a distance of 10 meters. The lanes are considered as obstacles to avoid and all obstacles are given a potential field value. The software then calculates the path of least resistance to follow. The compass readings are used to ensure the robot does not back track on its self.

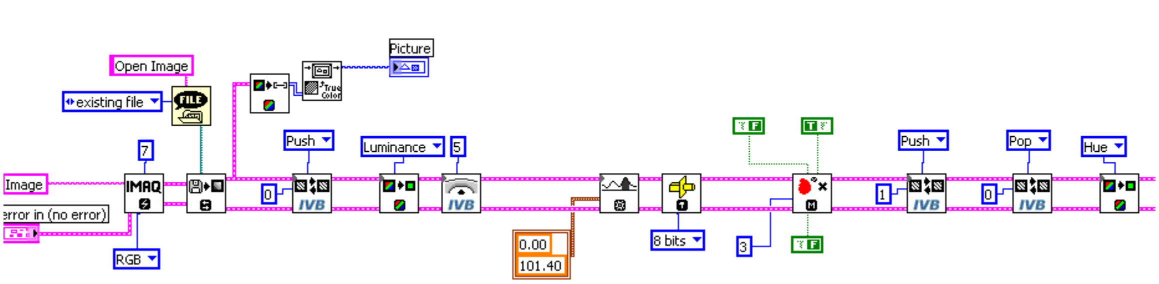

Figure 6: Sample LabVIEW code

LabVIEW is used to develop a state machine to take into account various conditions that the robot may find itself such as trap conditions or finding itself in such a position that both cameras have the same lane marking or no lane markings.

8.2 Lane and Pothole Detection

LabVIEW has colour image processing capabilities which are used to work in the Hue, Saturation and Luminous planes. This gives us the advantage of working in varying light conditions as the robot can eliminate the effects from excessive lighting by applying various filters. Various algorithms were tested using LabVIEW's Vision Builder using images of extreme and normal cases. Once a good algorithm was found it was converted into a Virtual Instrument and tested in real time.

Figure 7: Comparison of acquired image and processed result

8.3 Global Positioning based Navigation

The GPS navigation challenge is approached in 3 steps. The GPS readings are first converted into an x,y coordinate in meters using a conversion factor. This conversion factor is obtained by running a calibration program at the origin, to set this position to 0,0. The target GPS readings are then converted into meter coordinates using the same calculated conversion factor. The robot navigates to the target by storing its previous position and reading its current position and using these values to calculate a bearing. This bearing along with the bearing information from a digital compass are used to make the appropriate adjustment in the robot's direction to get to the target location. The algorithm also takes into account obstacles when choosing the direction to point the robot. The obstacles are detected using the ultrasonic sensor array and as in the autonomous challenge, the path of least resistance is chosen.

Section VIX: Performance Predictions

9.1 Robot Navigation

ALVIN IV's ultrasonic sensors successfully detected obstacles 15 to 1 feet away from the sensors. The ultrasonic sensors can see obstacles as small as 1cm approximately 5 feet away. The IEEE 1394 cameras are used for line detection and the algorithm was tested on extreme conditions with unclear lines, multiple shadows and varying light conditions amongst other tests. The robot was run in real time to ensure the processing can be carried out on two camera inputs simultaneously. The performance was estimated at 7 fps with lines detected 78% of the time in the most extreme cases. The GPS system was found to return reliable readings within a meter of target values. The implemented state machine takes into account various cases including possible traps and dead end conditions such as a line appearing in front of the robot or no lines detected between the two cameras.

9.2 Battery Life

The Sager notebook batteries last a total of 1hr with full electrical load. The lead acid cells used for the motor power are rated at 4.5Aph. The current required by the motors is 7A but due to the use of IM1007 Micro stepping controllers the maximum current draw was measured at 3A. Hence the motor batteries have a life of at least one hour. The GPS receiver and Vesta slave system run on separate 9.6 volt batteries rated at 1600mAH. The GPS receiver battery lasts for at least an hour of normal usage, while the vesta battery lasts for approximately 1.5 hours of continuous usage. The 4 ultrasonic sensors takes in 0.24A when the four sensors are fired sequentially, a 700mAH battery will last about 2hrs.

9.3 Ramp Climbing Ability

ALVIN-IV with its high torque motor was able to easily climb a ramp placed at an angle of 20 degrees to the horizontal ground. Climbing a 15 degree incline should not be a problem for the vehicle.

9.4 Speed

The maximum speed of the vehicle was calculated to be 3mph. However the optimal speed of the vehicle for maximum torque was found to be just under 1mph. Acceleration from zero speed causes a motor resonance at very early speeds requiring great care to be taken during acceleration.

9.5 Stopping Distance

The stopping distance for ALVIN-IV at an incline of 25 degrees was found to be 3ft at its maximum speed of 3mph. The high holding torque at the wheels of the robot (6870oz-in @ 1000 full steps) allows the vehicle to be stopped quickly and at a very short distance.

Section X: Safety Considerations

The robots light weight at 99lbs is easy to carry and transport. Two individuals can carry the robot at full load with the 20lbs payload. All the wires are correctly earthed and switches and controls are placed in easy access to individuals. Extra wire length is tied down and clipped to the frame. The robot body is made from molded plastic, so there is no chance of accidental shock from the batteries. The batteries are fastened down with industrial strength Velcro for quick replacement. The use of the mechanical e-stop placed at the rear center of the robot and the remote estop that can be used from a distance as far as 1000ft makes the vehicle safe.

Section XI: Sponsors

- Intelligent Motion Systems Inc.
- Bayside Motion Group
- Connecticut NASA Space Grant Consortium
- National Instruments LabVIEW
- Industrial Safety & Supply
- Thales Navigation
- Trinity College
- Travelers Insurance
- Teknicircuits Inc.