

Artemis

Vehicle Design Report

Autonomous Vehicle Team of Virginia Tech
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REPORT PREFACE

The Artemis vehicle entered in this year's competition is physically identical to the vehicle entered last year. As a result, the attached report is a duplicate of the report submitted last year for Artemis. Only minor changes have been made to Artemis's navigation algorithms and software. We submit this report according to competition rules with the hope that we will be eligible to compete in the performance events.

1 – INTRODUCTION

This report describes the design of the Artemis vehicle, submitted by the Autonomous Vehicle Team of Virginia Tech into the 7th Annual International Ground Robotics Competition. Artemis is a rebuild of one of Virginia Tech’s submissions to the Ground Robotics Competition, previously named Nevel. The Artemis design team retained the best and most innovative features of Nevel, including the zero turning radius differential drive train and a scanning laser obstacle detection system. The team also addressed several shortcomings of the previous design and added several new innovations and features. The Artemis team contributed over 4500 person hours for design, fabrication and testing throughout the project. Artemis is named after the mythical goddess of the hunt, because of the vehicle’s exceptional follow-the-leader ability.

2 – DESIGN PROCESS

2.1 – Design Methods

In developing a complex product such as an autonomous vehicle, the design process becomes critical to the organization of the design team and to the ultimate success of the design. A variety of methodologies have been developed for this purpose. The Artemis team elected to adopt the simple but well tested “Seven Stages of Engineering Design” developed by Sandor¹. Figure 2.1 shows the seven stages graphically. As noted by Sandor, design is not a linear process and iteration and backtracking are likely to occur.

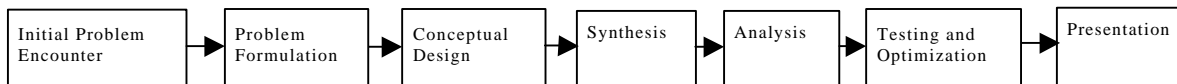


Figure 2.1 – The Seven Stages of Engineering Design

The Initial Problem Encounter occurred on the first day of the semester, when the faculty advisors challenged the team to build a vehicle capable of winning all four events at the 7th Annual IGRC (obstacle course, debris course, follow-the-leader and design competition). Many of the detailed objectives that followed can be found in the project timeline in section six of this report.

Early in the design process, the team decided to modify the Nevel vehicle entered in last year’s competition rather than starting a new design. Although the Nevel vehicle was innovative and was an excellent base design, major design changes were needed to enhance the vehicle’s performance. These design concept modifications produced a much-improved vehicle named Artemis.

The basic criteria considered in the design process were safety, simplicity, reliability, durability, and adherence to the competition rules. With these aspects in mind, and to reduce the number and size of components on

¹ Sandor, G.N., “The Seven Stages of Engineering Design,” Mechanical Engineering, April, 1964, pp. 21-25.

the vehicle, the team decided to replace Nevel's bulky PC with a laptop computer. This made the overall layout simpler and made components more accessible, which eases installation and maintenance on the vehicle. Additionally, the team spent considerable design time reducing the overall size and weight of the vehicle.

2.2 – Design Team Organization

All of the design work on Artemis was done as a team, such that each member had equal input into the design process. This interdisciplinary team-oriented design served two purposes. First, the involvement of several people with different backgrounds resulted in the implementation of innovative ideas. This would not be as likely if a few people of the same discipline were working on the design. Second, with every team member involved in the design of the entire vehicle, everyone had a good understanding of the interplay between various systems while working on a vehicle subsystem.

2.3 – Computer Aided Design Tools

After an initial conceptual redesign, computer aided design was used to create detailed views and the component placement on the vehicle. Computer-aided mechanical designs were created using Autodesk AutoCAD™ Release 14. The extensive use of AutoCAD™ allowed the team to easily test and manipulate alternate designs. The team also used cardboard mockups of mechanical components to double-check the proposed design before actual implementation. Electrical system layout was done using Visio™, a general purpose computer-aided layout package.

3 – MECHANICAL SYSTEM

3.1 – Base Vehicle Frame Design

The base frame of Artemis is a compact T-beam structure that rigidly attaches the industrial motors and gearboxes while providing support for the rest of the vehicle.

This small steel T-frame is the structural base for the entire vehicle. The motors and gearboxes are bolted directly to the T-frame assembly and the caster wheel

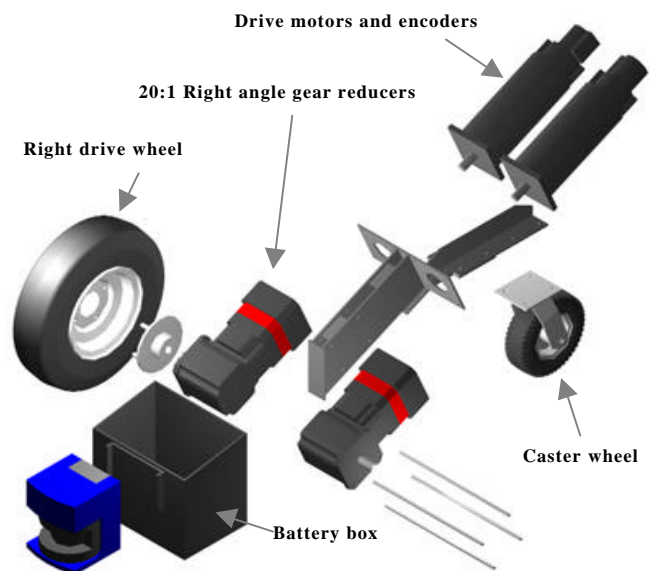


Figure 3.1 – Exploded view of vehicle's base structure with attached laser range finder

mounts to the extension on the back of the T-frame. Mounting points for the upper body of the vehicle and the battery box are located on plates welded to the frame. This innovative frame design is strong and rigid, and it provides Artemis with a small stable footprint and a high power-to-weight ratio.

3.2 – Drive Train

The drive train of Artemis uses two Kollmorgen 24-volt 32-amp brush-type DC servomotors, mounted in a differential configuration. This gives the vehicle a zero radius turn capability. Each motor is rated at 1.5 horsepower continuous, giving Artemis a total power of 3 horsepower. Each drive motor transfers power directly to a drive wheel through a Thomson-Micron DuraTRUE 90-degree 20:1 gearbox. The gearbox shafts are directly coupled to sixteen-inch wheels using custom-made hub assemblies. With all components onboard, the vehicle's center of gravity is located slightly behind the front wheels, giving Artemis excellent traction.

An important feature incorporated in the design of Artemis is the use of fail-safe disc brakes integrated within each motor assembly. During operation, the braking system is held in a disengaged state by electromagnets. Upon any type of emergency stop or loss of power, the electromagnets lose power and the brakes are engaged, bringing Artemis to a rapid stop. Each fail-safe brake provides approximately 10 ft-lb of holding torque at the motor, or 200 ft-lb of holding torque at each wheel. This holding torque is sufficient to hold the weight of the vehicle against rolling under any condition. BEI quadrature encoders mounted axially above the fail-safe brakes provide position and velocity feedback to the motor controller and main computer. The use of a standard commercial drive assembly (motor, encoder, fail-safe brake and gearbox) results in a clean, durable and reliable package.

3.3 – Upper Body Design

During the design of the upper body assembly, the team focused on keeping the design safe, durable, and weatherproof. Safety was addressed, in part, by using only non-conductive, rigid materials. A rigid fiberglass composite sheet is used as the base for the upper body, on which the rest of the components are mounted. The ¼” composite sheet is bolted to the steel T-frame. Dark gray rigid ¼” plastic (PVC) sheet is used to construct the main upper body, where most of the electrical components are mounted. Adjacent plastic sheets are connected by sturdy formed plastic (PVC) angle braces, which are fastened by plastic epoxy. The PVC body is attached to the composite sheet base with angle fiberglass and epoxy. Most of the electrical components, including the motor controller, motor amplifiers, power bus, and E-stop circuitry, are mounted within the PVC box. Hook and loop-type fasteners are used where possible to mount devices such that components can be easily placed and removed to facilitate installation and maintenance. An additional sheet of plastic forms the lid, which mounts securely over the main body to protect

electrical components from the environment. A large 24-volt DC brushless fan is mounted inside the box to provide cooling for the electrical components. A small camera tripod is mounted to the upper body lid, onto which the video camera is secured. The use of a tripod provides a stable mount for the camera, while allowing the camera to be repositioned if desired.

The team decided to use a laptop computer instead of a full-sized PC to minimize weight and power consumption on the vehicle. To protect the laptop computer from the weather and to enhance the view of the screen in the sun, a weatherproof plastic cover was designed and built for the rear of the vehicle. Additionally, a see-through cover can be placed over the exposed rear end of the vehicle to completely seal the laptop from the weather, while allowing the user to view the LCD screen. In the event that the clear cover is being used, auxiliary keyboard and mouse ports are accessible from the vehicle's rear panel.

The battery box and laser range finder are mounted to the base T-frame on the front of the vehicle. A plastic shell completely covers the battery box and signal connections to the laser range finder. This shell is easily removable to provide quick access to the battery pack, which may need to be changed often. This design feature was added to address the problem that some vehicles have had in the past, where batteries are very difficult to access, making vehicle operation cumbersome.

4 – ELECTRICAL SYSTEM

4.1 – Overview

In designing Artemis' electrical system, the team focused on providing a solution that is safe, reliable, effective, and serviceable. Before physical implementation, the team designed the entire electrical layout using Visio™. This approach produced an organized physical layout of the electrical system with no rewiring required. The electrical layout is shown in Figure 4.1.

The exclusive use of a 24-volt DC power system aided in the simplicity of the system. By using only 24-volt DC power, power inverters are eliminated from the system design. The 266 MHz Pentium II laptop computer contains an internal battery and power supply, reducing the current load on the drive batteries. Only signal connections are made between the computer and any component of the vehicle. This eliminates the problems that may occur when connecting the vehicle and computer power systems. The computer batteries provide over four hours of continuous use, and the batteries can be swapped without shutting down the computer. The video camera also has an internal battery pack, providing it with up to twelve hours of continuous use.

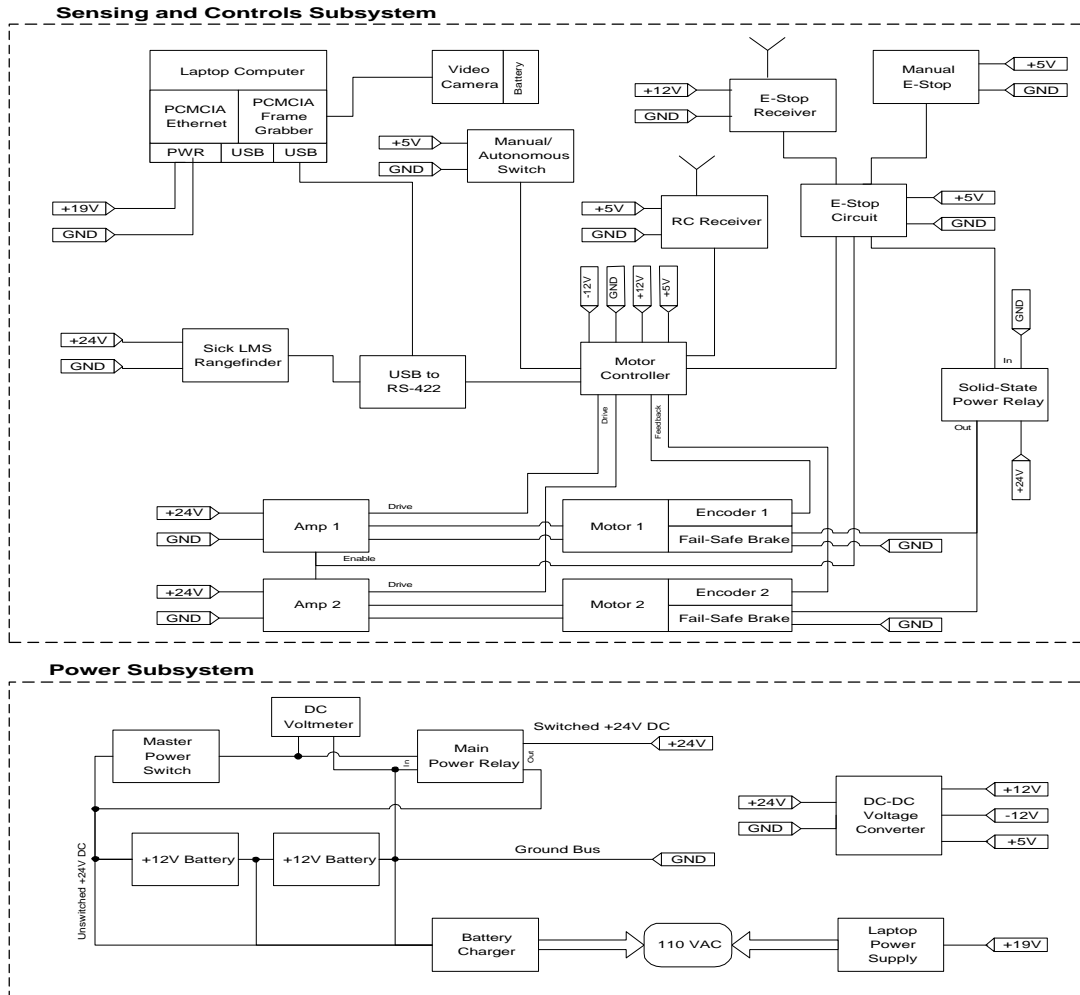


Figure 4.1 – Artemis Electrical System Layout (designed with Visio™)

The computer connects to the rest of the vehicle via the Universal Serial Bus (USB) port, the serial port, and a PC card frame grabber. A joystick, an external keyboard and/or a mouse may also be attached. A small port replicator is permanently attached to the vehicle, to which the serial cable, USB cable, keyboard cable, mouse cable, and joystick cable are attached. The laptop snaps onto the port replicator and is immediately connected to the entire vehicle. This allows the laptop to be attached with a minimal number of wire connections.

In order to simplify the electrical system, all of the motor control electronics and remote and E-stop circuitry is contained within a single ‘component box’ that has several 9-pin connectors (DB-9) and sealed 4-pin AMP connectors for easy attachment and removal. In this way, most of the complex circuitry is hidden from view and day-to-day operation. Additionally, the entire electrical system can be disassembled in only a few minutes, which greatly enhances the serviceability of the vehicle.

4.2 – Power System

Artemis' main power system consists of two 12-volt 28 amp-hour maintenance-free batteries wired in series to provide a 24-volt DC power source. The batteries are packed in pairs and permanently wired to a sealed AMP power connector. The mating connector is permanently attached to the front of the vehicle's main compartment. This simple interface is safe and weatherproof. Additionally, when one battery pack is drained, it can be quickly removed and replaced with another pack.

Inside the main compartment, there is a direct connection from the battery connector to another AMP connector, to which a battery charger may be attached, allowing quick charging when the vehicle is not moving. The battery charger is waterproof, and it is connected via a reverse-sex sealed AMP connector. The charger is mounted on the front of the vehicle and can be easily removed if desired.

The main battery power is routed through a 300 volt, 100 amp continuous relay that is controlled by a key switch on the back panel of the vehicle. This serves as the main power switch for the vehicle, and no current flows from the batteries when the relay is not activated. A small digital voltmeter is located on the back panel of the vehicle to monitor battery voltage during operation.

Some vehicle subsystems require +5, +12 and -12 volts for operation. This power is supplied by two small switching power supplies within the custom built component box which convert 24-volt DC to +5, +12, and -12 volts DC. Two power supplies are used to provide a margin of safety and redundancy. The subsystems are arranged such that the current load on each power supply is approximately equal.

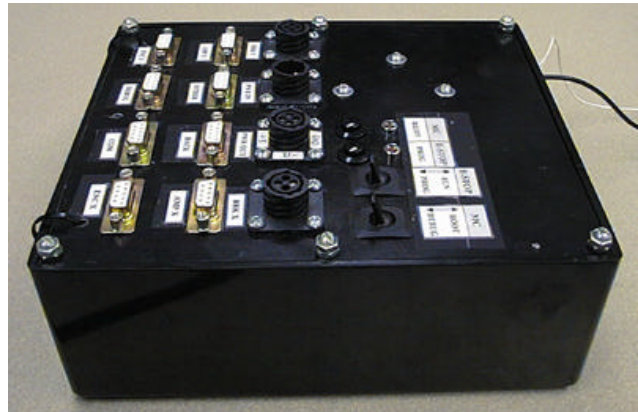


Figure 4.2 – Component box with labeled signal and power connections

4.3 – E-Stop System

Artemis has several parallel systems, each of which can E-stop motion. E-stopping involves removing power from the fail-safe brakes, causing them to lock, and inhibiting the amplifiers from powering the motors. The fail-safe brakes are powered by a 12-amp 24-volt DC solid-state relay, which is controlled by a simple hardware logic circuit. The remote system, manual switch, and software switch all input into the logic circuit, any of which can cause the vehicle to E-stop. The use of a simple logic circuit eliminates the possibility of E-stop failure due to mechanical problems or software errors. Power failure to the E-stop circuit also causes the vehicle to E-stop.

The remote E-stop subsystem is implemented via a commercially available product, the Street Smart Security Hunter 6-Channel Receiver. This device uses a small remote transmitter, similar to a garage door opener transmitter. The transmitter-receiver pair negotiates communication via pseudo-randomly changing codes, which eliminates the possibility of inadvertent E-stops due to electrical noise in the environment. The range of the system is 200-600 feet in open air.

Manual E-stop is implemented via a large red button located in the center rear of the vehicle. The button serves as one of the inputs into the E-stop hardware logic circuit. If the switch is depressed, or is somehow ripped from the vehicle, the E-stop will be activated. The controlling software also has the capability of causing an E-stop, if desired. This may be used when controlling the vehicle with the joystick, or if the software detects an unrecoverable situation.

4.4 – Sensing

Artemis uses two sensors to obtain information about the external environment, a color video camera and a Sick LMS laser range finder, and encoder feedback. The video camera inputs directly into a PC card frame grabber in the laptop computer. The frame grabber snaps a picture of the camera image and returns an array of Red-Green-Blue (RGB) values to the controlling software for image processing.

The Sick LMS communicates with the computer serially, via the USB to RS-422 serial protocol converter. The Sick LMS scans 180 degrees in a plane approximately 8 inches from the ground and returns a sequence of 361 values representing radial distances at ½ degree increments.

4.5 – Control System

Artemis' control system is centered on a Motion DAC-AE motor controller built into the 'component box' within the main compartment of the vehicle. The motor controller consists of a 40 MHz Intel compatible microprocessor and a multi-axis motion control chipset, assembled by Tern, Inc. The microprocessor is standard C language programmable and has several digital I/O lines for additional purposes. This microprocessor communicates with the motion control chipset, which performs the closed-loop control of Artemis' two motors.

A switch on the back panel of Artemis is the input into the microprocessor that selects between manual and computer control. Manual operation indicates that the microprocessor should use the R/C remote receiver output to control the vehicle. Computer control indicates that the microprocessor should receive motion control commands from the laptop computer via the RS-422 (serial) port.

In manual mode, two custom-programmed PIC microprocessors interpret the output signal from the R/C receiver and output an 8-bit digital value, proportional to the position of the transmitter flight stick. The Motion DAC-AE microprocessor inputs the two digital values for use as remote manual-control velocity inputs. The best method of implementing manual control has been to use differential control. That is, one input channel controls average vehicle speed, while the other controls relative speed of the two wheels. This allows for easily driving straight and for a zero turning radius (ZTR). Another method of manual operation available is the use of a joystick through the computer to control the vehicle.

The motion control chipset sends analog signals to two 24-volt 100 amp Advanced Motion Control pulse width modulated (PWM) servo motor amplifiers. The analog signal represents the desired torque to apply to the wheels. BEI quadrature encoders provide feedback for closed loop motion control, which is handled internally by the motion control chipset.

5 – SOFTWARE DESIGN

5.1 – Design Goals and Requirements

The major goals approached in the development of Artemis' software were to make the software fast, effective, reliable, easy to use, and able to be upgraded. Ideally, the speed of the software should be limited only by the speed of the input/output hardware on the frame grabber. Artemis' software has been written using Microsoft® Visual C++ 6.0 under Windows 98™. It uses many Graphical User Interface (GUI) enhanced options. Intermediate stages of image processing and laser processing, as well as the map building and navigation stages can be viewed graphically during operation for testing. The Artemis team realized that the vast majority of the vehicle's operational lifetime is spent testing, and has created the software accordingly. The software also needed to be easily upgraded and maintained, such that problems can be diagnosed and new ideas can be tested.

5.2 – Image Processing

Artemis sees the world primarily using a Hi-8 color camcorder, which is typically positioned such that the field of view is roughly 4 to 20 feet ahead of the vehicle. The camcorder has a built-in color display to aid configuration and debugging of software. Additionally, the camcorder can record a test run and then replay the tape for later analysis and testing. The output from the camcorder is input into the PCMCIA (PC card) VideoPort Professional Frame Grabber, which grabs a 200-pixel by 200-pixel 8-bit grayscale image.

The 200-pixel by 200-pixel image size was found to be a compromise between processing time and desired resolution. Several basic algorithms are used to pre-process the image for later analysis. The image is first de-glared,

which tends to reduce the glare effects of the sun at the top of the image. The image is blurred to remove noisy pixels and then an active thresholding algorithm is used to produce a strictly black and white image. White pixel clusters that do not fit the characteristics of a lane marker (e.g. too wide or irregular in shape) are assumed to be glare or obstacles and are removed for the purpose of line detection. A median filter is used to eliminate spurious pixels that may remain in the image. After pre-processing the image, lines representing the lane markers ahead of the vehicle are extracted using a simple least-mean-squared total regression algorithm which determines the line that best fits the remaining white pixels. A 2D-to-3D transform is used to transform the lines determined from the image into lines in 3-dimensional space relative to the vehicle. The line information is later passed to the sensor fusion portion of the code for integration into the global map.

In addition to lane marker extraction, the vision system attempts to recognize known types of obstacles in the image. A connected component-labeling algorithm is used on the previously thresholded image to determine clusters of adjacent pixels that may represent obstacles. Statistical data such as pixel counts, central moments, and bounding rectangles are generated for each cluster then they are classified as obstacles or non-obstacles accordingly. The obstacle locations are passed to the sensor fusion code to be put into the global map.

5.3 – Laser Processing

The Sick LMS Laser Range Finder scans in a plane approximately eight inches from the ground. This distance provides clearance over most low-lying objects, such as grass, while reliably detecting obstacles as short as twelve inches. The range finder scans 180 degrees and returns a sequence of 361 data points representing radial distance from the range finder at $\frac{1}{2}$ degree increments. These data can easily be plotted and seen graphically once it arrives in the laptop via the serial port.

The Artemis software uses a simple and innovative method for obstacle detection with the range finder, based on the first derivative of the data it returns. Using this technique, the software can determine which data values correspond to part of an object, and which do not. Based on the distance to the object, and the angular dimension of the object, the approximate size and placement of the object can be determined relative to the vehicle. If the object dimensions are within predefined limits, the obstacle information is sent to the sensor fusion and map-building code.

5.4 – Sensor Fusion and Map Building

Artemis statistically fuses its sensor data over a short amount of time. The software remembers several previous sensor data samples, including detected lines and obstacles, and uses this accumulated data to navigate.

When each sample is collected, it is marked with the current vehicle position and heading estimates. Then, as new position and heading estimates are calculated, based on feedback from the motor controller, the relative position of a given sensor data sample to the vehicle is known. Accumulating several data samples effectively weakens bad data (such as falsely detected obstacles) and strengthens good data (a repeatedly detected line will appear in the map several times). This allows Artemis to make better navigation decisions based on data sampled over a small period of time. After a certain number of data samples, old data values will be overwritten by new data values, removing them from further consideration in navigation.

5.5 – Navigation

Artemis uses an advanced navigation algorithm that involves several ‘behaviors’. In general, Artemis will operate using the ‘line following’ behavior, where navigation decisions are made using a point-charge planning algorithm. The point-charge planning algorithm is an intuitive algorithm in which a target point is generated by considering the vehicle to be a charged point, and all lines and obstacles to have certain electric fields associated with them. Based on the available map information, the algorithm plots a path ahead of the vehicle being pushed away from lines and obstacles by imaginary forces. The vehicle is then directed to move toward a target point at the end of the plotted path.

It has been found that the point-charge algorithm works for most cases presented in the competition, but the algorithm is not made to handle all cases. In the event that the navigation software recognizes one of these cases, the software can switch to a different behavior. For example, Artemis attempts to identify horizontal and nearly horizontal lines detected in the image. The point-charge navigation algorithm does not handle this case very well, so Artemis switches behaviors to ‘course-seeking’ mode. In the course-seeking mode, Artemis stops moving forward, and pivots left or right while attempting to identify which way it should travel. Once Artemis has reestablished one or two lines that are nearly vertical in the field of view, the software switches back to the line following behavior. These and several other behaviors enable Artemis to handle a wide variety of situations during competition, such as dead-end traps and steep inclines.

5.6 – Hardware Control

Because of the distributed nature of the electrical system, hardware control of the vehicle from the system software is relatively simple. The motor controller microprocessor handles all of the details associated with controlling the motion of the vehicle. The software on the laptop computer needs only to send desired velocity commands to the motor controller using a serial interface.

Additionally, because the motor control microprocessor is able to E-stop the vehicle using digital outputs, the laptop software is able to E-stop the vehicle by communicating with the microprocessor. Likewise, the microprocessor is able to detect when the system has been manually E-stopped, and can communicate this information back to the laptop computer.

6 – DESIGN ISSUES

6.1 – Safety

Safety remained the highest priority during the design and construction of Artemis. Fail-safe brakes lock the motor drive shafts unless power is provided by an E-stop system implemented in hardware, which can be activated by remote, manual switch, or software. The entire upper body of Artemis is made from non-conductive composite and plastic (PVC) materials, lessening the chance of dangerous power system problems. Sealed maintenance-free batteries, an enclosed battery box, and water-resistant quick connect plugs prevent many dangerous battery situations. Female plugs on all powered components prevent inadvertent shorting of power to ground and foolproof plug orientations prevent improper power system connections. All other electrical connections on Artemis are water-resistant and are well labeled to reduce the chance of an improper connection. Covered cooling fans and ventilation ports remove buildup of heat or moisture, while protecting sensitive components from the weather. The laser range finder operates using a Class I laser diode that is ‘eye safe’, and is completely enclosed in a protective case. Artemis is physically capable of achieving a forward or reverse velocity of up to 8.5 mph. However, the top speed is limited to 5 mph in low-level software routines, such that software glitches in high-level routines can not cause the vehicle to violate the speed limit.

6.2 – Innovations and Features

Several innovative design features have been included during the design of Artemis. The zero turning radius differential design and the fail-safe brakes have been retained from last year’s vehicle. The newly designed vehicle shell is modular and provides easy access to frequently used systems, while remaining weatherproof. This was made possible by extensive use of CAD and layout packages during the initial stages of design. Location of the 20-pound payload at the lower rear of the vehicle lowered the overall center of gravity, reducing the chance of tipping forward. A covered rear panel on the vehicle gives the operator access to several important vehicle functions, while being protected from the environment.

Artemis uses a single 24-volt DC power bus, which eliminates the weight of an inverter and the danger associated with AC power. Quick-swap battery packs with unique connectors make the operation more convenient

and less prone to errors. A small onboard battery charger allows Artemis to conveniently charge without changing batteries (whenever an outlet is accessible). Weather-resistant plugs between all electrical components make operating and servicing the vehicle safe and easy. All wiring is simple and modular, allowing a failure to be quickly diagnosed and repaired. The distributed nature of Artemis' control scheme allows the laptop computer to be dedicated to sensing processing while a separate microprocessor is dedicated to motion control. This also allows the vehicle to operate in manual mode without the laptop present, via the remote R/C transmitter. A new remote E-stop system provides longer range while being less sensitive to noise.

The extensive use of the Graphical User Interface (GUI) capabilities of Windows 98 and user interface enhancements make Artemis' software easy to use. Innovative image processing techniques and laser range finder data processing give Artemis an advantage over similarly equipped systems. The vehicle's sensor fusion and map building capabilities allow the software to use past information in making future navigation decisions.

6.3 – Reliability and Durability

Artemis has been designed for rugged outdoor use, starting with the T-Frame base that is constructed from 3/16" carbon steel plate. Industrial motors and gearboxes provide sturdy drive train, while 16-inch tires allow the vehicle to easily negotiate rough terrain. The laptop computer is inherently more rugged than the standard PC on many robotic vehicles. The rigid composite and plastic (PVC) frame enclose and protect the more sensitive electronic components from weather or impact damage.

6.4 – Problems and Solutions

The extensive use of CAD and layout software in the initial design stages prevented many potentially serious setbacks in the development of Artemis. In the design phase, several problems were addressed and solved. One of these problems was component matching. For Artemis, the laser range finder and the motor controller used a total of three serial ports. However, the laptop computer has a limited number of standard input/output (I/O) ports. Using a Universal Serial Bus (USB) to RS-422 converter from the laptop solved the problem.

Despite extensive CAD design work, some problems are not evident until a component is actually fabricated and tested. This was the case with the vehicle's caster wheel placement. After the vehicle tipped in last year's competition, the team decided that the caster wheel placement was too close to the front wheels, resulting in a vehicle footprint with marginal stability on rough terrain. This led, in part, to large oscillations as the vehicle navigated through bumpy terrain. The problem was corrected by building a longer and more rigid caster wheel

support. The new caster wheel support also enabled us to position the required payload at the bottom of the vehicle, thus lowering the center of gravity.

6.5 – Predicted Performance

For safety and compliance to competition regulations, Artemis’ top speed is software-limited to 5 mph. The vehicle’s two 1.5 horsepower motors can easily maintain 5 mph up a 15% incline. Although Artemis can maintain 5 mph throughout the entire course, the team expects the software to be able to navigate the course reliably while moving at approximately 2.5 mph. This speed is competitive with winning entries from past years in the competition. Because the video camera and computer use independent power supplies, a fully charged vehicle battery pack will operate Artemis for over one full hour. If the user shuts off the vehicle during the small periods of time between consecutive tests, which can be done with no appreciable delay in operation, the battery life can be extended further. The laptop computer can operate for up to 4 hours when using two batteries at the same time. The laser range finder and zero turning radius drive system give Artemis a superior advantage, particularly in the follow-the-leader bonus competition. Artemis can follow a target object at a fixed distance, at speeds ranging from 0 to 5 mph.

6.6 – Project Timeline

As part of the design process, it was essential to follow a structured design timeline to ensure on-time delivery and integration of the various mechanical and electrical systems. Table 6.1 outlines the Artemis team design approach and associated time frames.

Fall Semester			Spring Semester		
Beginning	Middle	End	Beginning	Middle	End
Sept 1: Team organization completed	Oct 8: Acquire laptop computer	Nov 24: Upper body shell completed	Jan 19: Reformulate semester goals and benchmarks	Mar 2: Battery box cover fabricated and sealed	April 20: Demonstate vehicle at local exhibition
Sept 10: Acquire new frame grabber	Oct 13: Software implementation begun	Nov 26: Component box completed	Jan 26: Design for camera tripod mount completed	Mar 4: Autonomous operation for simple situations	May 5: Design report updated after review
Sept 15: Preliminary electrical design completed	Oct 15: Finish caster wheel modification	Dec 2: Wiring completed	Feb 4: Component box lid and body complete	Mar 11: Laser range finder integrated into software	May 15: Finalize vehicle testing and modifications
Sept 17: Acquire remote E-stop	Oct 27: Finalize electrical design	Dec 3: Manual mode working	Feb 9: Image processing and line finding complete	Mar 25: Rear cover and clear lid complete	May 19: Final design report completed
Sept 29: Software architecture design begun	Nov 3: Acquire PVC for upper body	Dec 8: Preliminary design report completed	Feb 18: Camera tripod mount complete	April 15: Behavior based navigation added to software	June 5-7: IGRC Competition

Table 6.1 - Design Timeline

6.7 – Team Organization

The Artemis team is comprised of electrical, mechanical, and computer engineers from all academic levels.

The roster is shown in Table 6.2.

Names	Position	Major	Academic Level
David Mayhew	Vehicle/Sensing and Controls Leader	EE	Graduate
Khalil Nasser	Mechanical Leader	ME	Senior
Patrick Coleman		EE	Senior
Peter Hanson		EE	Graduate
Kevin Ball		ME	Junior
Charles Lamb		ME	Freshman
Edward Burgess		EE	Sophomore
Ryan Fong		CpE	Sophomore

Table 6.2 - Artemis Team Roster

6.8 – Cost

Table 6.3 shows a complete cost breakdown for all the components of Artemis. Donated items are noted as such. Also, totals are shown for donated and purchased items.

Item	Vendor	Cost	Status	
			Purchase	Donation
24 VDC, 28 amp hour batteries (6)	Battery Outlet	\$218	X	
24 VDC Servo Motors	Kollmorgen Industrial Drives	\$7,980		X
120A5 Servo Amp, PWM Output	Advanced Motion Controls	\$800		X
100A5 Servo Amp, PWM Output	Advanced Motion Controls	\$800		X
Pentium II 266 MHz Laptop Computer	Quantex Microsystems Inc.	\$2,699	X	
MRT VideoPort PCMCIA Frame Grabber	The Imaging Source	\$250	X	
EdgePort II USB to RS-485 Converter	B&B Electronics	\$259		X
Motion-DAC-AE Version Motor Controller	Tern Inc.	\$1,100	50%	50%
Hunter 6-Channel Relay Receiver	Home Automation Systems	\$180	X	
Power Relay	Newark Electronics	\$37	X	
5 amp Dual-Pro Battery Charger	Charging Systems Int.	\$250		X
MF3106F18-1S Encoder Plugs (3)	BEI Industrial Division	\$60	X	
90-Degree DuraTRUE Gearboxes 20:1 (2)	Thomson Micron	\$1,600		X
8" Swivel Caster Wheel	Trendlines	\$23	X	
Scanning Laser Range Finder	SICK Optic Electronics	\$3,400		X
16" x 4" Trailer Tires (2)	B.F.Goodrich	\$60	X	
Assorted Hub Assembly Parts	CT Farm and Country	\$53	X	
Frame Steel		\$27	X	
Fiberglass Sheet	AIN Plastics	\$90	X	
Sealed Power and Signal Connectors	AMP	\$89		X
PVC Sheet and Connector	USA Plastics	\$90	X	
Fiberglass for Battery Box		\$60	X	
Assorted Electrical Connectors and Wire		\$28	X	
Assorted Hardware (screws, bolts, etc.)		\$25	X	
Totals		\$20,178	\$4,450	\$15,728

Table 6.3 - Cost Breakdown for Artemis Vehicle