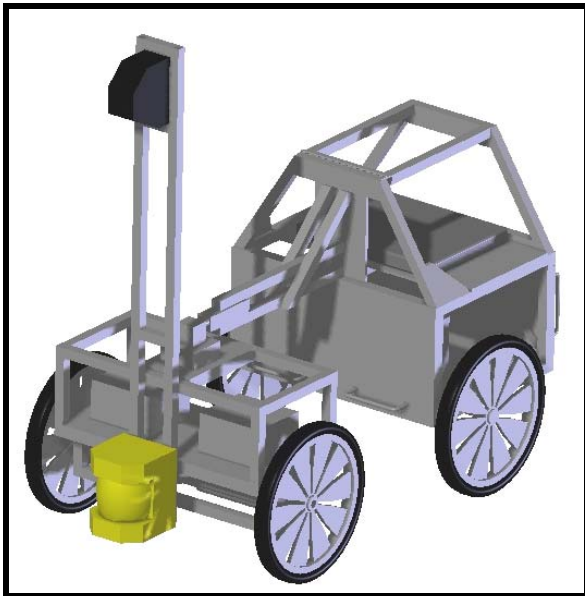


GEMINI

VIRGINIA TECH *ayt*



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Required Faculty Advisor Statement

I certify that the engineering design of the new vehicle described in this report, Gemini, has been significant, and that each team member has earned six semester hours of senior design credit for their work on this project.

Charles F. Reinholtz, Department of Mechanical Engineering, Virginia Tech

1 Introduction

The Autonomous Vehicle Team of Virginia Tech is pleased to present Gemini, an innovative new vehicle designed specifically to compete in the Intelligent Ground Vehicle Competition (IGVC). Gemini is a novel, articulated, twin-body vehicle with excellent maneuverability and terrain following capabilities. The name Gemini reflects the “twin” bodies of our vehicle, inspired by the well-known constellation of the same name.

Innovation and attention to detail are the hallmarks of Gemini’s design. Gemini exemplifies an effort to develop a professional and stable research test bed that will serve as a solid foundation for current and future competitive design efforts. To this end, the overall vehicle design stresses safety, serviceability, ruggedness, and utility. These design objectives are achieved through innovative design features that have been implemented within the mechanical, electrical, and navigational systems onboard Gemini.

2 Innovations

Gemini, shown in Figure1, is based on a unique two-body platform that provides zero-radius turning capability along with exceptional stability on uneven terrain. The keys to this enhanced performance lie in the drive system and in the two-degree-of-freedom joint connecting the front and rear platform. Independent motors drive the two front wheels, and a vertical axis of rotation between the body sections allows the front platform to pivot relative to the undriven rear platform. The steering pivot point is centered directly between the front wheels, allowing the front platform to turn about its center (a zero-radius turn) without moving the rear platform. A second axis of rotation between the body sections allows the front body to roll relative to the rear body. This allows Gemini to keep all four wheels on the ground on extremely uneven terrain. In essence, the rear platform follows the front platform like a trailer, but with one important difference. Since there is no joint to allow pitching motion between the front and rear, the rear platform gives the front platform stability in the fore and aft direction, which allows the front “towing” platform to have only two wheels. Steering is accomplished by driving the two driven front wheels at different speeds, just as with any other differentially steered vehicle.



Figure 1: Gemini in a Turn

Another important, but less obvious, innovation is the use of integrated amplifier, controller, and brushless DC motors to power the two driven wheels. The use of brushless motor technology provides an increased power-to-weight ratio compared to brush-type DC motors. In addition to providing a low center of gravity and a compact and tightly integrated overall design, these “smart motors” give an important secondary advantage. They allow the use of a notebook computer to directly command wheel motion through a single serial cable. This eliminates the need for a computer chassis that can accommodate motor controller cards or the use of external motor controllers as well as bulky external amplifiers. This design has eliminated the motion control

issues that plagued previous notebook-computer-based vehicle designs. We have also implemented a firewire camera that interfaces directly with the notebook computer, again eliminating the need for a frame grabber card and a larger computer chassis.

We have also implemented a more robust power system that provides the vehicle run times of nearly five hours with one set of batteries. Depleted batteries can be quickly swapped with replacements to provide continuous operation. Furthermore, Gemini builds upon the recent success of our autonomous vehicle platforms with the exclusive use of National Instruments (NI) LabView software. The use of LabVIEW greatly simplified software development and systems integration.

The chassis of Gemini is designed for easy access to all vehicle components, including the electrical system, power system, computational hardware, and sensors. The entire vehicle is weather resistant with all moisture and particle sensitive components housed in protective enclosures. The vehicle electrical system employs industrial standard components and connections, which provides a clean and reliable power and logic networks.

3 Design Process

Team Gemini employed the well-tested design process shown in Figure 2. Although the steps are shown sequentially, iterations to all the previous steps inevitably occur along the way. As our design evolved, we continually tested it against the previously established requirements to ensure that our final product would satisfy the requirements of our customers.



Figure 2: The Design Process Used to Create Gemini

3.1 Development of Customer Needs

The primary purpose of Gemini is to successfully compete in the 12th Annual, 2004 IGVC. Many of our customer needs are well defined in the 2004 IGVC rules and objectives. We also interviewed members of previous teams to help understand what features users typically found to be important. For example, previous competitors cited short battery life as a major limitation in vehicle testing and in waiting in the queue to compete. They also noted that small diameter caster wheels impaired mobility, especially at discontinuities such as the leading edge of the ramp. We specifically addressed both of these issues in designing Gemini.

3.2 Investigation of Previous Vehicle Designs

Initially, the team studied the design and operation of two successful Virginia Tech IGVC entrants: Zieg and Optimus. Intensive study of these vehicles enabled the team to identify the following elements that are critical to success: a stable platform, a short turning radius, a compact component layout, a reliable/adequate power system, and effective control and navigation software. Furthermore, the research helped the team to determine which vehicle design features required improvement. Successful design features from these previous vehicles that were included in Gemini’s design were the differential drive mobility scheme and use of National

Instrument's LabVIEW software for all programming tasks. Vehicle weight, run time, motor control issues, and the assembly of the electrical system were all aspects of the previous designs identified for improvement.

3.3 Establishing Target Specifications

After studying previous designs, the team generated comprehensive target specifications for parameters such as size, weight and runtime. Safety was the most important objective for the new vehicle, so a number of the detailed specifications addressed safety issues such as fuses, grounds, fault protection and safe modes of failure. In particular, the team wanted to improve the power system used on previous vehicles, by increasing the capacity of the batteries to minimize the number of battery exchanges during operation. Considering previous runtimes of 45 minutes, a target minimum runtime of 2 hours was established.

3.4 Final Design Concept

Through brainstorming and collaborative design meetings, ideas and concepts to meet the target specifications were generated. The team decided to implement electrical, sensor, and software systems similar to designs used on previous vehicles. We also decided to develop a radically different mobility platform, computer system and power system. Since the mechanical system design of Gemini was a significant departure from previous vehicle designs, a great deal of effort was devoted to the mechanical aspects of the design. Initially, a scaled LEGO model of the vehicle design provided proof of concept. Additional mechanical analysis of key design features, such as the articulated joint, helped to assure the feasibility of the design.

Before beginning construction, 3-D CAD models and renderings of the vehicle design were created using SolidWorks and Rhinoceros 3-D studio. Renderings of the solution are shown in Figure 3. Planning and design of the electrical system was carried out utilizing Microsoft Excel and Visio 2000. Use of these software design methods and tools provided a solid foundation and clear plans as the team moved towards the fabrication phase.

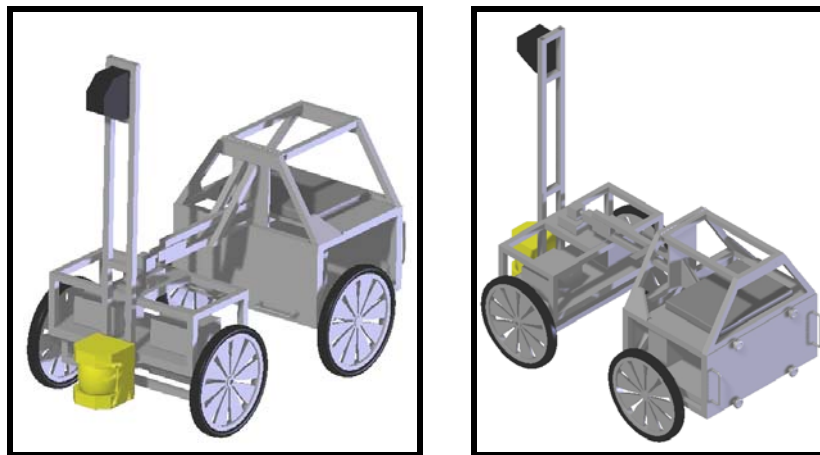


Figure 3: SolidWorks Rendering of Gemini

3.5 Team Organization

The team divided into three sub-teams to focus efforts on key sections of the vehicle. Although each person had a particular set of responsibilities, all team members assisted with tasks outside of their designated areas. Figure 4 details the organizational structure of Team Gemini with three sub-teams being the frame, electrical, and software groups. A total of 3,255 hours of labor were invested in the development of Gemini.

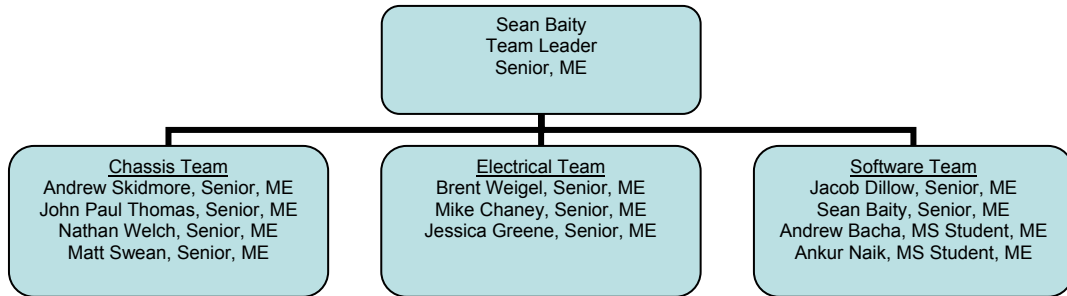


Figure 4: Organizational Chart of Team Gemini

4 Frame and Chassis

Gemini’s frame was constructed from 1” square aluminum tubing with 1/8” wall thickness. Figure 5 shows CAD renderings of the frame design as well as a photograph of the vehicle frame during early mobility testing.

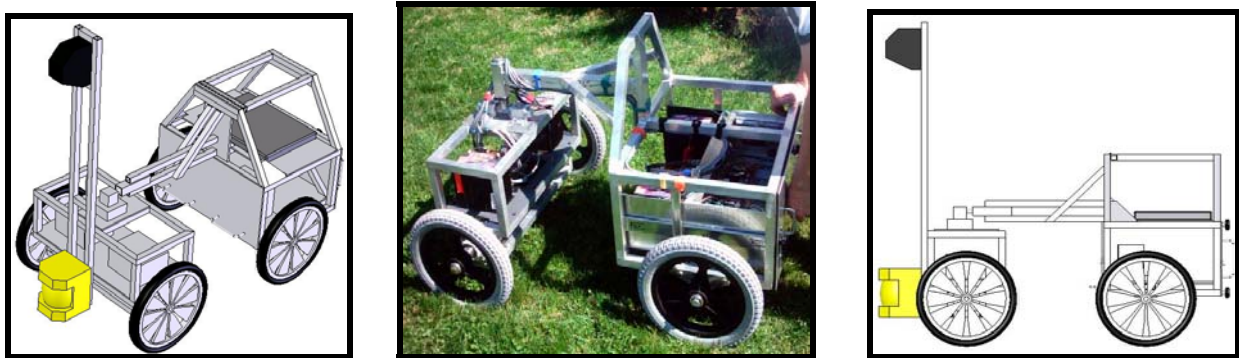


Figure 5: CAD Models and a Photograph of the Base Frame.

The welded aluminum chassis ensures a sturdy base for mounting other vehicle components. Figure 6 shows how the sliding electrical enclosure has been integrated into the frame design. This small innovation makes the electronic components accessible in a matter of seconds.

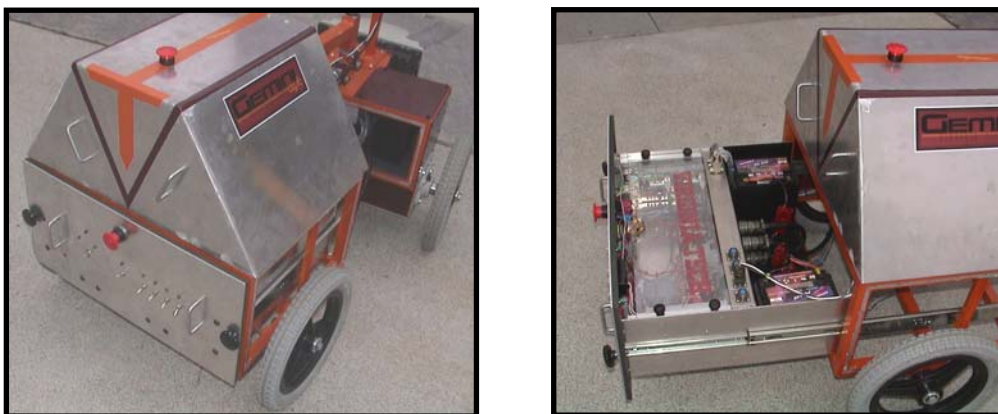


Figure 6: Integrated Electrical Box Closed (left) and Extended (right).

4.1 Drive Train

Drive power to propel Gemini is provided by two QuickSilver SilverMax 34HC brushless DC servomotors. Each motor provides a maximum 0.6 horsepower at 1.82 ft-lb of torque with a continuous stall torque of 3.52 ft-lb. Integral with the motors are 10:1 reduction NEMA 34 gearheads. When coupled with a Timkin polycarbonate locking bearing and a custom machined steel hub, the motor and gearhead provide a simple and reliable drivetrain as shown in Figure 7.

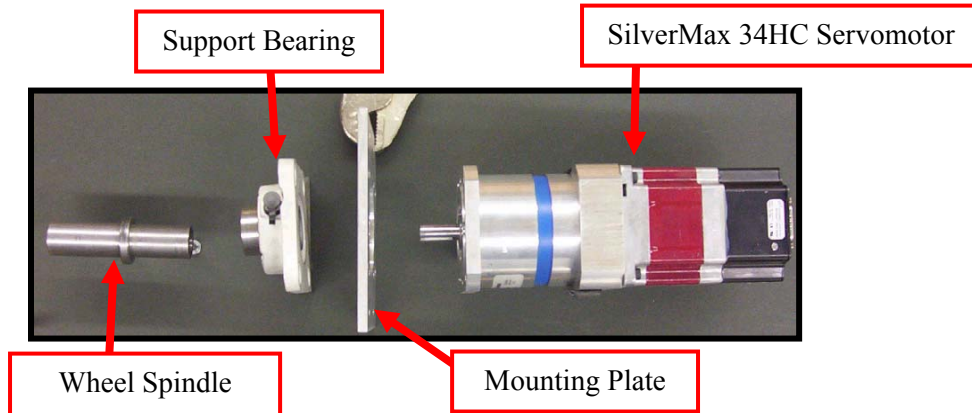


Figure 7: Vehicle Drivetrain Assembly (Without the Wheel).

4.2 Steering and Terrain Following

The body motions permitted by Gemini's two-degree-of-freedom joint are illustrated in Figure 8. The two independent front drive wheels are differentially driven to both propel and steer Gemini. The vehicle can make a zero-radius turn until the drive section is perpendicular to the carriage section. The desire to minimize twisting of the cables running between the front and rear body sections limits this motion. The entire vehicle can turn within a circle having a radius of 45.5". The excellent torque provided by the two brushless motors permits Gemini to traverse inclines up to 22° (40% grade). With 4" of ground clearance and polyethylene skid pads under the front body section, the vehicle should easily overcome potholes and other obstructions that might be encountered on the IGVC courses.

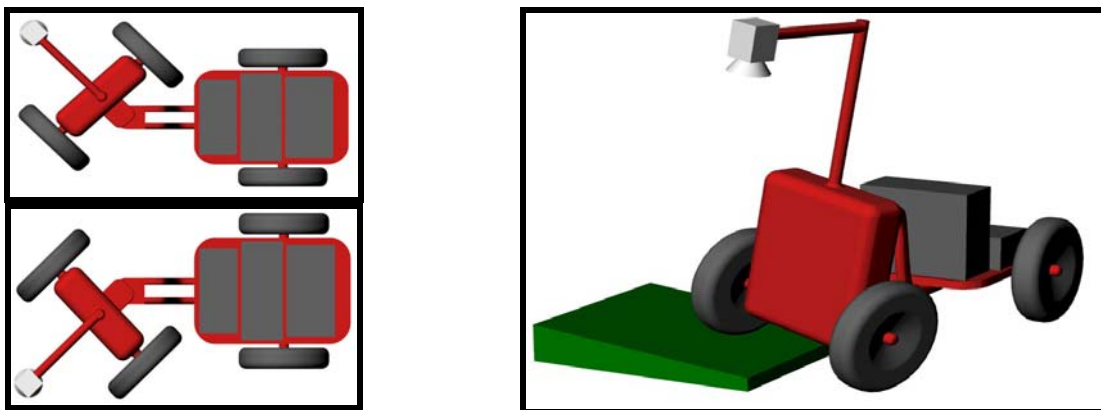


Figure 8: Renderings Showing the Steering and Twisting Action Provided by the Articulated Joint.

4.3 Stability and Vibration Isolation

Gemini's four-wheel configuration and low profile provides for a stable vehicle platform. The 14" composite wheels with low rolling resistance pneumatic tires provide for a cushioned ride. The two-degree-of-freedom articulated joint enables the vehicle to maintain four points of contact with the ground while on uneven terrain. A front to back weight distribution of 55/45, allows for effective traction on the forward drive wheels.

Initially, problems were encountered in the implementation of the articulated two-degree-of-freedom joint between the body segments. In initial fabrication, the joint construction resulted in a kinematic singularity when the vehicle attempted to execute a 90° zero-radius turn, which requires the front body segment to be perpendicular to the rear segment. In this position, the two revolute joint axes would become collinear, and the front section of the vehicle would fall over. The solution to this problem was to reverse the location of the two axes, such that the steering axis always remains vertical. The initial design concept was correct, but the order of rotation was reversed during the initial construction. The final result was a stable two-degree-of-freedom joint.

The onboard notebook computer is isolated from shock and vibration by rubber shock absorbers that cushion the aluminum panel on which it rests. Integrated rubber stop blocks prevents the computer from separating from the mounting plate. A welded and formed aluminum hood protects the computer from outside elements. These features help make the vehicle reliable and robust during autonomous operation.

4.4 Physical Parameters and Handling of Vehicle

Gemini, in its completed, competition ready form weighs 218 lbs. This is 18 lbs heavier than the initial design specification. The extra weight was part of a compromise to increase the performance and overall utility of the vehicle. Iterating back to customer needs in our design process, we determined that desired battery life and computational speed were the more important to our customer than vehicle weight. The additional weight can be partially attributed to the addition of a 14 lb high-performance notebook computer that was nearly twice the weight used for initial weight estimates. Despite the final disparity in vehicle weight, Gemini is lighter and easier to transport than either of the vehicles entered in the 2003 IGVC by Virginia Tech. A small reduction in weight was achieved along with a gain in performance by using aluminum construction throughout the vehicle, implementing lightweight dry cell lead acid batteries, and exploiting the excellent power to weight ratio provided by the DC brushless motor packages.

To facilitate the transport and handling of Gemini, the open composite hub design of the front and rear wheels provide four convenient lift points. These points provide means for two people to lift the fully loaded vehicle into the back of a van or truck. Additionally, an integrated remote control circuit allows direct operation of the drive motors without the need for an onboard computer.

5 Electrical System

The electrical system on Gemini is an also an innovative aspect of its design. Team Gemini considered safety, practicality, and reliability from initial design concept to final implementation. Many of the power distribution and control problems that hampered previous designs have been effectively eliminated. The system

first avoids faults by eliminating common modes of failure; if a fault does occur, the design facilitates quick recovery.

5.1 Electrical Safety

Gemini's electrical system team made safety the highest priority in both vehicle construction and function. In addition to following a standard convention, all wiring is enclosed in vinyl insulation or shielded cabling, and all wires terminate in insulated screw-down terminal blocks. Additionally, in-line fuses prevent injury and equipment damage in case of an accidental high-current discharge. Most importantly, the electrical system features an emergency stop capability that can be activated through a wireless controller, software control, or tactile buttons on the vehicle's exterior. When activated, the fail-safe emergency stop system immediately stops the motion of the vehicle by effectively cutting power to the motors and engaging a fail-safe friction brake.

Onboard battery cells use Absorbed Glass Mat (AGM), dry cell lead acid technology that prevents acid leakage or outgassing during operation. The AGM battery technology is by far the safest configuration of deep cycle lead acid battery cells. Since all hazardous chemicals are absorbed into a dry glass mat matrix, the batteries on Gemini could be oriented in any position or even mutilated without the fear of leakage.

5.2 Physical Layout and Configuration

Overall, electrical components are arranged in a manner that facilitates simple interconnection. The front body section includes Gemini's motors and offers the best platform for mounting the camera and laser rangefinder, since it provides an unobstructed forward view. An integrated electrical box and computer are located in the rear body of Gemini. The rear section houses all aspects of the onboard power and logic systems as well as all user interfaces. Two batteries are mounted in the front portion of Gemini and two are mounted in the rear section of the vehicle. Industrial strength Velcro securely attaches the batteries to the mounting positions on the frame.

5.3 Motors

The QuickSilver brushless DC servomotors contain fully integrated motion controllers and amplifiers. The motors are significantly lighter, more powerful, and more compact than traditional brushed DC servomotors systems. Detailed and precise motor control is performed internal to the drive system, making the entire drive system modular and easy to control via RS-232 serial communication.

5.4 Sensors

Four separate sensing devices enable Gemini to navigate in the context of its surroundings. These devices are listed and described in Table 1. The camera and laser rangefinder are employed in the Autonomous Challenge portion of the competition to locate the pathway boundaries and various physical obstacles. The digital compass and GPS allow Gemini to determine its heading and location while the laser rangefinder provides data on the position of obstacles during the Navigation Challenge.

Table 1: Summary of the Four External Sensors Used in Competition.

Device	Function
Digital Firewire Camera	Determines pathway boundary and negative obstacles
SICK LMS-221 Laser Range Finder	Detects obstacles
PNI TCM2-20 digital compass	Determine vehicle heading
Novatel Differential Global Positioning System (GPS)	Determine absolute global location

5.5 Power System

Four Hawker Odyssey PC 535 sealed lead acid batteries provide onboard electrical power for Gemini. Each battery weighs 12.5 lbs and provide 13 A-hr deep cycle capacity. Four batteries provide two independent voltage buses to power the motors and sensors independently. This dual bus architecture reduces noise and eliminates disparity in power distribution common to previous electrical system designs. The sensor power bus provides a 12 and 24 VDC supply. Each battery includes a genderless universal connector that allows it to be plugged and unplugged to the electrical system easily when recharging is needed. These connectors also offer a safe way to connect the batteries to the electrical system by preventing accidental polarity mismatch. Additionally, these durable connectors can handle high cycle rates as well as the high current potential provided by the battery cells.

Modular power cabling allows for multiple alternative battery configurations. Alternate configurations that range from the basic 4-cell configuration up to 10 cells can be utilized to provide higher bus voltages or increased capacity. This design feature provides for added flexibility to meet alternative, task specific, requirements. One 24 VDC, 20 amp battery charger is used to charge depleted batteries as needed. It can fully recharge two batteries from an 80% depth of discharge in less than two hours.

5.6 Electrical Box

Gemini's electrical box is incorporated in the rear section of the vehicle and is securely mounted on compounding sliding drawer runners, as shown previously in Figure 6. This drawer allows the entire electrical system to be extended from the rear of the vehicle for rapid inspection and maintenance. Multiple levels of access are designed into the electrical box to meet the varied needs of maintenance. If repair or inspection is required, pulling the drawer from the rear of the vehicle provides direct access to the electrical box.

5.7 Electrical System User Interface

User interface with Gemini's power system occurs primarily on the rear control panel of the vehicle, also shown in Figure 6. The rear panel of Gemini's electrical box drawer contains six switches and eight LED indicators. The switches toggle main vehicle power as well as power to each of the individual sensors. This facilitates rapid power cycling in case of sensor fault. Red and Green indicators provide visual confirmation of system status.

6 Software

Gemini uses separate software algorithms for the Autonomous Challenge and the Navigation challenge. Both algorithms were developed using National Instrument's LabVIEW software. By using the intrinsic control and analysis aspects of LabVIEW, it was possible to rapidly design, implement, and test navigation and control code.

6.1 Computer

Gemini's onboard computer is a Pentium 4 class, 3.2 GHz, notebook that resides on the rear section of the vehicle frame. The computer communicates with the motors and sensors by either USB, through a serial to USB converter, or an IEEE 1394 firewire port. The operating system used on the machine is Microsoft Windows XP professional.

6.2 Software Operation

The user interacts with the navigational software by means of a graphical user interface, LabVIEW virtual instrument (VI), front panel that provides means to alter system settings as well as inspect vehicle performance data such as motor bus voltage, motor temperature, and torque produced by the motor. The navigational software is triggered prior to each competitive run and subsequently operates Gemini autonomously.

6.2.1 Autonomous Challenge Algorithm

The navigation algorithm for the autonomous challenge is based on a vector field histogram (VFH) approach. The white boundary lines of the course are detected using an edge detection method on a processed and filtered image captured from the firewire digital camera. The processing of the image includes altering the exposure and gain settings for the digital camera as well as extracting the blue plane from the color image acquired by the camera. Correction of the image is also necessary to account for the spatial distortion introduced by the wide-angle camera lens. An example of a processed image of the autonomous challenge course that would be used during the navigation algorithm is shown in Figure 9. The result of the image processing is a high contrast image that highlights the white boundary lines in the field-of-view of the digital camera.



Figure 9: Example of Course Boundary Lines in a Processed Image.

An annular region of interest is then established on the processed image where an edge detection function will search for the presence of the high contrast course boundary lines. The outcome of the edge detection process is the polar coordinates (magnitude and angle) of the white lines relative to the vehicle position. Figure 10 shows the rectangular and VFH data generated by the edge detection on a processed image. The laser

rangefinder provides polar coordinates of obstacles present in the forward path. This data is simply overlaid onto the VFH to provide a composite image of all obstacles and boundaries observed by the vehicle.

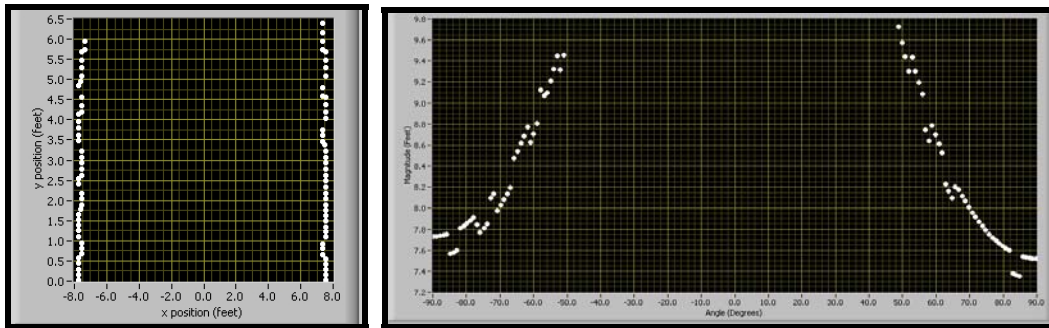


Figure 10: Results of Edge Detection Shown in Rectangular Coordinates (left) and a Vector Field Histogram (right).

With both the computer vision and laser rangefinder data creating an array of the magnitude and angle of known obstacles, the navigation algorithm determines the best heading by first determining if there is a “gap” in the angle data. A gap in the angle data corresponds to an open path for the vehicle. The largest perceived gap is then taken as the best path and the average angle of the gap is then used as the forward heading of the vehicle. If there is no gap present in the angle data set, the software assumes that the vehicle is observing a single line and tracks parallel to the line. With the most severe case is the execution of a zero radius turn when the vehicle is confronted with a blocked path. With the desired heading established, the navigation algorithm then determines the desired wheel speeds required and commands the motors to those wheel speeds. The overall autonomous challenge navigation algorithm is outlined in Figure 11.

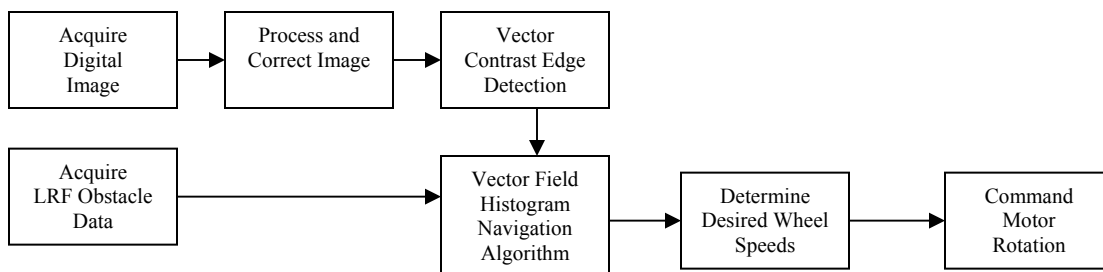


Figure 11: Autonomous Challenge Navigation Decision Process Flowchart.

6.2.2 Navigation Challenge Algorithm

A combination of speed and accuracy is required to compete successfully in the navigation challenge. The navigation challenge software uses inputs from the differential GPS, the digital compass, and the laser rangefinder. Current heading information is obtained from the digital compass, and current vehicle position is obtained from the differential GPS receiver. The current position and the known position of the next desired waypoint are used to determine a desired heading. The laser rangefinder provides obstacle avoidance information.

The navigation challenge algorithm can be described in three parts. First, the waypoints are analyzed to find an efficient order in which to reach each point. Next, a third degree polynomial curve fit determines the desired vehicle wheel speeds to reach the next point on the course at a desired forward velocity. Finally, any obstacles detected by the laser rangefinder alter the forward course of the vehicle in order to take a safe route around the obstacle. Figure 12 outlines the decision process for the navigation challenge algorithm.

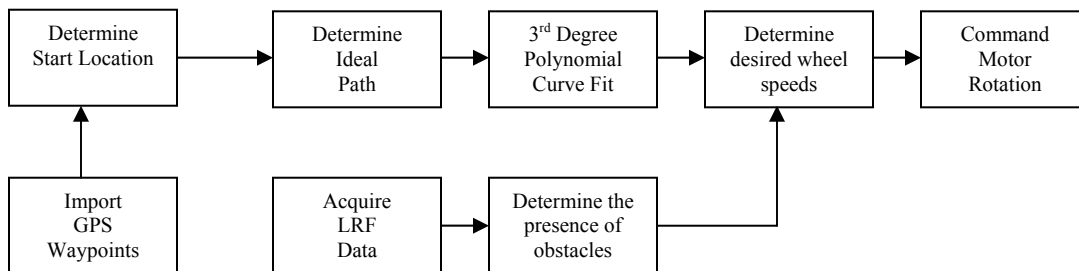


Figure 12: Navigation Challenge Decision Process Flowchart.

7 Predicted Vehicle Performance and Results

7.1 Speed

The Quicksilver brushless DC motors equipped with 10:1 reduction gearheads have a no-load output speed rating of 300 rotations per minute. When using 14" tires, the vehicle can obtain a maximum rated speed of 12.5 mph. In testing, the vehicle was able to achieve actual speeds of about 10 mph. In competition, the motor control software will enforce a strict 5 mph speed limit for both the autonomous and navigation challenges.

7.2 Ramp Climbing Ability

Although the largest ramp that will occur during competition is specified to be 15% grade (8.5 degrees), testing of Gemini sought to determine the vehicle's ability to overcome larger inclines and other ground discontinuities that would provide even larger effective grade resistance. During testing it was possible to drive the vehicle, via the remote control function, up inclines of nearly 40% grade (21.8 degrees). Furthermore, it was possible to carry a payload, in excess of 200 lb up this grade. Additionally, Gemini is able to overcome abrupt discontinuities such as concrete curbs of more than 4 inches in height.

7.3 Reaction Time

During both the autonomous challenge, the software refreshes at a rate of 15 Hz, or once every 66.7 ms. This refresh rate is limited by the firewire camera data rate. To calculate a conservative reaction time estimate, the processing time for the autonomous challenge will be considered. Specifically, the data transfer time from the camera to the computer is 17.6 ms. Furthermore, the process time of the vision software and the data command transmit time to the motors is 66.7 ms and 1.40 ms, respectively. The total time to collect sensor data, execute the navigational algorithm, and issue control commands to the motors is 85.7 ms. The reaction time of the vehicle motors to respond to the motion commands varies based on the current and desired wheel speeds and motor load.

However, the navigational algorithm accounts for this variation by implementing a distance threshold for which objects are considered obstacles.

7.4 Battery Life

The two 13 A-hr battery banks that provide power to the motors and sensors were tested and shown to have an effective runtime of about 5 hrs. The onboard notebook computer can be powered by an integrated Lithium-Ion battery pack that yields a runtime of approximately 1.5 hrs depending on notebook power and display settings. Alternatively, the notebook can be powered by the sensor battery bus, which increases the nominal runtime for the notebook to nearly 5 hrs. The nominal runtime of Gemini operating in full autonomous mode is approximately 5 hrs.

7.5 Obstacle Detection Distance

There are two sensors that detect obstacles during operation. The scanning laser rangefinder serves as the primary obstacle avoidance sensor. The scanning laser rangefinder has a range of 80 m, but the current navigation software ignores obstacles that are further than 4 m away from the front of the vehicle. This range is sufficient to allow consideration of multiple obstacles and obstacle trends prior to determining the best forward path of the vehicle. The computer vision system can also be used to identify barrels and potholes, but this approach has only proven to be reliable for obstacles within a distance range from 1 to 2.5 m in front of the vehicle.

7.6 Dead Ends, Traps, and Potholes

Gemini uses a resourceful method of dealing with barrel traps and potholes. To avoid obstacles, the positions of positive obstacles such as barrels as well as negative obstacles (i.e. potholes), are essentially combined with the acquired camera image. This allows all obstacles to be considered equally by the vector field histogram navigation algorithm. If the vehicle encounters a dead end, the vehicle performs a near zero radius turn until a suitable path is found.

7.7 Accuracy of Waypoint Navigation

Preliminary testing shows Gemini can consistently navigate to GPS waypoints to within less than one meter, given good quality GPS signals and a reliable differential correction. Specifically, the Novatel GPS unit provides for sub decimeter accuracy when coupled with OmniStar HP correction service. Additionally, the GPS unit runs at a 20 Hz sample rate, which provides a significant advantage during high speed GPS navigation.

7.8 Accuracy of Headway and Lateral Deviation Maintenance

The digital compass used on Gemini displays a ± 0.5 to ± 1 degree heading accuracy depending on the amount of tilt experienced by the unit. The GPS unit is able track the global position of Gemini within centimeters of its actual position and continually augments the navigation algorithm to assure the lateral deviation is minimized.

8 Testing and Simulation

Testing of Gemini was completed in three phases: initial mobility testing, software simulation, and the course trials. Initial mobility testing, using tethered joystick control, provided insight to the functionality and

ruggedness of Gemini. An innovative IGVC competition software simulator, developed using LabVIEW, allowed development of navigation algorithms independently of a specific vehicle platform. This software simulation provided a decisive advantage by providing a platform-independent controlled test environment to evaluate the viability of software solutions. Once the vehicle platform had been finalized and the software developed, testing of the navigational software algorithms was conducted on outdoor courses that emulated IGVC competition scenarios.

9 Safety

The design and fabrication of Gemini stressed the safety of those working on the vehicle along with the safety of operators and spectators at competition. For example, sharp edges and corners were rounded, and the lead acid batteries were insulated from the surrounding metal. Body panels and secure access panels further provide security and safety by preventing unintended access to the interior of the vehicle. A failsafe friction brake that actuates in the absence of electrical power will prevent the vehicle from rolling during an emergency stop situation. Moreover, the vehicle software facilitates Gemini’s autonomy and controllability by considering desired operational limits that will reduce or eliminate safety hazards. Intrinsic to the navigation software are drive wheel speed and turning rate limitations that eliminate rapid vehicle movement that could be hazardous to observers or the vehicle itself.

10 Vehicle Component Costs

During the design and fabrication process of Gemini, there was a concerted effort to minimize the cost of the vehicle design through pursuit of industry donations and support. This goal was largely achieved, and the majority of the vehicle development cost was eliminated or reduced due to generous sponsor donations. Table 2 provides the retail cost of each component and actual costs incurred by the design team.

Table 2: Summary of Vehicle Component Cost.

Components	Retail Cost	Cost to Team
Sager NP8990 Laptop	\$2,435	\$0
(2) QuickSilver DC Brushless Motors	\$2,450	\$2,450
(6) Hawker PC 535 AGM Dry Cell Lead Acid Batteries	\$480	\$480
Novatel DGPS Unit	\$7,995	\$2,995
Sick LMS-221 Scanning Laser Range Finder	\$5,930	\$5,930
Unibrain Firewire Digital Camera	\$82	\$82
PNI TCM2-20 digital compass	\$700	\$0
National Instruments RS-232 Serial to USB converter	\$200	\$0
Electrical Components	\$685	\$285
Aluminum Frame and other frame materials	\$400	\$400
(4) Low Rolling Resistance Composite Nylon Wheels	\$75	\$75
Total	\$21,432	\$12,697

11 Systems Integration

Gemini’s various subsystems were designed to be integrated from the outset of the design process. The exclusive use of National Instrument’s LabVIEW allowed us to create standard VI’s (virtual interfaces) for

reading sensors and controlling the motors. Once a Virtual Instrument has been created, it be manipulated as one of the component blocks in a block diagram. For example, the once the laser rangefinder VI was created for the Autonomous Challenge, the same VI block was used to interface with the laser rangefinder and process its information in the Navigation Challenge software.

The selection of the integrated Quicksilver drive system and the firewire camera further simplified integration. Gemini is a tightly integrated, yet modular, vehicle platform based on cohesive LabVIEW-based product architecture. Attention to design intent and a concerted focus on eliminating known problems has resulted in reliable communication links, fault resistant power distribution, and an impressive product package. In essence, the problems of system integration were addressed at the design level, eliminating the usual component interfacing problems.

12 Conclusion

Gemini is a fully autonomous robotic vehicle, designed and manufactured by engineering students at Virginia Tech. Gemini is based on a novel two-body articulated platform that combines the maneuverability of a differential drive system with the ability to traverse rough terrain and ascend steep grades. The use of an integrated brushless motor, controller and amplifier system and a firewire camera simplified the overall design, allowing a notebook computer to directly read all the sensors and command the drive motors through existing communication ports. Through continued testing and development, Gemini stands as an example of a robust, effective, and professionally constructed autonomous vehicle. By following a methodical engineering design process, and using the latest software tools, Team Gemini was able to create a vehicle that should compete favorably in all three events at the 12th annual IGVC.