Gemini 2005 Design Report

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Required Faculty Advisor Statement
I certify that the engineering design of the 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.

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1. Introduction

The Autonomous Vehicle Team at Virginia Tech is proud to reintroduce Gemini, a fully autonomous ground vehicle for entry into the 2005 Intelligent Ground Vehicle Competition (IGVC). Gemini is a proven platform based upon solid functional performance and sound engineering design. Gemini has undergone significant updates to solidify the novel two-body articulated platform as one of the premier intelligent ground vehicles competing in the IGVC.

2. Innovations

Gemini returns to competition based on previous innovations such as an articulated platform, integrated "smart" motors, and reliable system architecture. Building upon previous successes, Gemini has been updated to meet the demands of the IGVC with more intelligence and refinement.

Reliability has been improved with the use of solid state power electronics and power conditioning to ensure uninterrupted operation. The exterior of Gemini has been enhanced to provide unmatched weather resistance and durability. Integration of a battery charger onboard the vehicle results in Gemini being a self-contained solution requiring only the remote control emergency stop and a standard extension cord as ancillary equipment.

The backbone of Gemini's intelligent capabilities is the innovative system architecture. The use of commercial off-the-shelf (COTS) system components provides Gemini with the ability to reliably acquire mission critical data. Furthermore, Gemini incorporates aspects into the design which facilitate the adoption of the Joint Architecture for Unmanned Systems (JAUS). Support of current JAUS implementation comes through the omni-directional 802.11b/g antenna that provides Gemini the capability to interface with other JAUS compliant systems.

3. Design Process

Constraints on time and resources in conjunction with the demands of the IGVC necessitate the implementation of a rigorous design process. Inherent in this design process are milestones and deliverables that hold the design team to a predetermined schedule and guide decision making. Milestones included identification of proposed improvements by November 2004, completion of detail design by January 2005, and completion of fabrication by March 2005. Testing and evaluation rounded out the academic year with a practical demonstration of all navigation abilities by May 2005.

3.1 Design team structure

The need to continue the development of Gemini and re-enter the vehicle into the 2005 IGVC prompted the formation of a design team charged with the improvement of Gemini. The team divided itself into three functional groups, as shown in Figure 1. In total, the Gemini design team has dedicated nearly 1,100 hours to developing the vehicle for reentry into the 2005 IGVC. This continues the initial 3,255 hours of work completed for the 2004 IGVC.

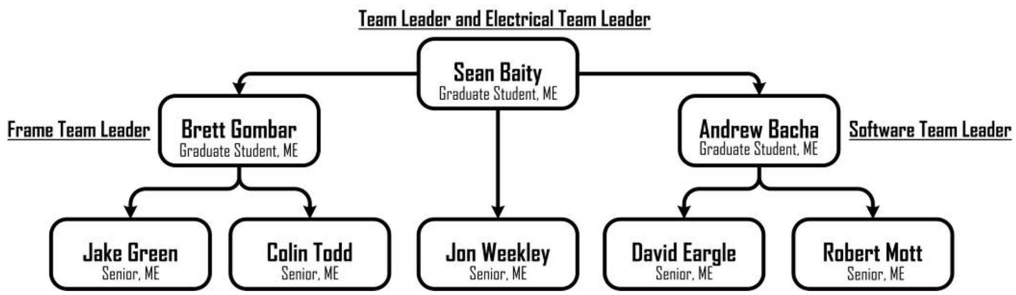

Figure 1: Functional decomposition of the Gemini vehicle design team.

3.2 Design Methodology

The Definition-Design-Produce (DDP) design approach used by the Gemini design team is shown in Figure 2. The definition phase leverages the unique aspects of design for the IGVC by incorporating competition rules and the experience gained from previous competitions. A holistic approach to design development is applied during the design phase and carried through to the produce phase where the vehicle is finally constructed and validated.

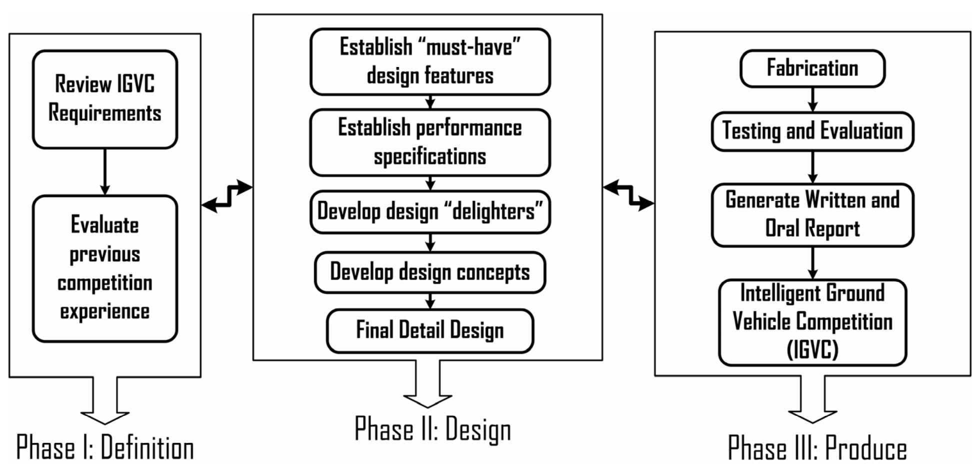

Figure 2: A detailed map of the iterative DDP design process

Since Gemini is a legacy design, particular attention was given to the development of design improvements addressing usability, reliability, and performance. Intense review during the definition phase highlighted that in practice, a removable battery power source proved to be a burden during competition and a viable alternative needed to be implemented. Furthermore, despite being one of the most reliable electrical systems ever developed at Virginia Tech, the reliance on electro-mechanical power distribution posed a longevity concern for overall vehicle sustainability. Moreover, the design team focused on updating algorithms to solidify Gemini's intelligent capabilities.

4. Chassis

The welded tubular aluminum frame of Gemini has proven to be a durable and reliable chassis. Major upgrades in the vehicle mechanical design include a compact electrical box, external cable management, an integral jack stand, and overall weather resistance. Supporting the translation from design concept to reality, 3-D solid models created in Solidworks were continually referenced to assure effective and efficient use of time and materials. Figure 3 highlights the progression of Gemini from conceptual model to final product.

Figure 3: Progression of the design of Gemini from 3-D CAD concept, initial mobility testing, 2004 IGVC entry, and 2005 IGVC entry (left to right).

4.1 Platform Mobility

The fundamental design of Gemini is a two-body articulated platform that provides zero-radius turning capability along with exceptional stability on uneven terrain. Gemini's four-wheel configuration and aggressive stance provide for a stable vehicle platform. Gemini offers the mobility afforded by three wheel vehicle platforms while exhibiting the stability Indicative of four wheel platforms. The two degree-of-freedom articulated joint enables the vehicle to maintain four points of contact and allows Gemini to conform to uneven terrain; it functions essentially as a suspension without springs. 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 while a vertical axis of rotation between the body sections allows the front platform to pivot relative to the non-driven rear platform as detailed in Figure 4. 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. Steering is accomplished by driving the two front wheels at different velocities. A second axis of rotation between the body sections allows the front body to roll relative to the rear body as demonstrated in Figure 5. This allows Gemini to keep all four wheels on the ground on extremely uneven terrain. Since the pitching motion between the front and rear is constrained, the rear platform gives the front platform stability in the fore and aft direction, which allows the front platform to have only two wheels.

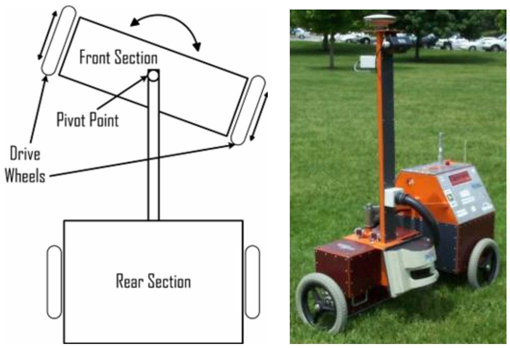

Figure 4: Detail of the steering method of Gemini.

Figure 5: Gemini demonstrating the unique mobility provided by the two degree-of-freedom articulated platform.

The desire to minimize the twisting of interconnecting cables restricts the continuous execution of zero-radius turns of the front section. The photo in Figure 4 demonstrates the practical limit of roughly 90° on the rotation of the front section relative to the rear. However, the degree of mobility and drive symmetry afforded by the implementation of differentially driven wheels allows Gemini to move in any direction from a fixed starting point despite the rotational limits.

4.2 Chassis Reliability

All interconnecting cables that transfer power and data between the front and rear sections of Gemini are enclosed in durable flexible IP68 rated conduit. The conduit in conjunction with the durable plastic paneling and weather stripping throughout the vehicle allows Gemini to operate in harsh environments without fear of damage to critical system components. This attention to weather resistance allows Gemini to compete in the IGVC rain or shine.

4.3 Drivetrain

Gemini is driven by two Quicksilver SilverMax 34HC-1 brushless DC servomotors. Each motor provides a maximum 444.7 watts (0.6 hp) at 2.47 N-m (1.82 ft-lb) of torque with a continuous stall torque of 4.77 N-m (3.52 ft-lb). Integral with the motors are 10:1 reduction NEMA 34 single stage planetary gearheads. When joined with a Timken polycarbonate eccentric locking bearing and a custom machined steel hub, the motor and gearhead provide a simple and reliable drivetrain.

4.4 Physical Parameters

Gemini exhibits a total deployment weight of 297 pounds and measures 0.914 meters (36 inches) wide, 1.575 meters (62 inches) long, and 1.829 meters (72 inches) tall. A front to back weight distribution of 62/38 allows for effective traction on the forward drive wheels. Gemini also exhibits an exceptional 51/49 lateral weight distribution adding to its sure footing. Gemini has a center of gravity 31.2 cm (12.27 inches) above ground level. The turning area of the Gemini platform has a radius of 1.156 m (45.5 in).

5. Electrical System

The electrical system on Gemini is an innovative aspect of its design. The design team 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. CAD systems such as Microsoft Visio and Protel DXP supported both design and fabrication.

5.1 Safety

The electrical system features fail-safe emergency stop capability that can be activated via wireless controller, software control, or a large tactile button on the vehicle's exterior. When activated, the emergency stop system stops the motion of the vehicle by effectively cutting power to the motors. All high current electrical components are electrically and physically isolated from interaction with the user in order to minimize opportunities for possible injury. Furthermore, onboard battery cells use Absorbed Glass Mat (AGM) dry cell lead acid technology that prevents acid leakage or outgassing during operation. Since all hazardous chemicals are absorbed into a stable dry glass mat matrix, the batteries on Gemini could be oriented in any position or even mutilated without the fear of leakage.

5.2 Electrical System Layout

As shown in Figure 6, the front body section is the ideal location for the placement of sensors while the rear section supports the control components of the design. The inclusion of a powered Firewire and USB hub in the front section of the vehicle allows for expanded sensor capabilities such as stereo vision modules, advanced data collection instrumentation, and other devices that can provide Gemini with the ability to perform a wide range of mission objectives and enhance IGVC performance. Upgrades to the data and power distribution on the front of the vehicle have reduced the number of cables spanning the gap between the front and rear section of Gemini from twelve to eight.

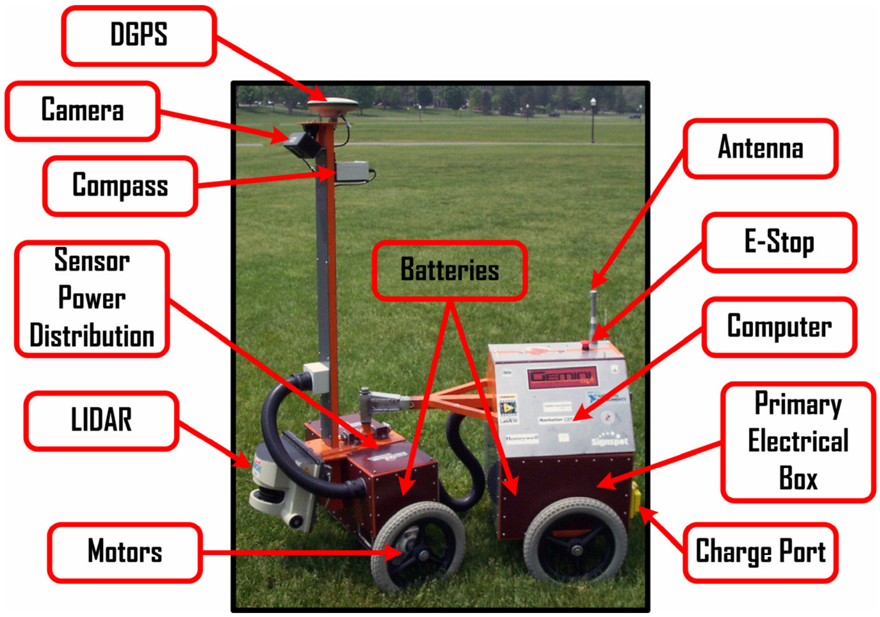

Figure 6: Diagram of the physical location of the key elements in the electrical system design.

5.3 Motors

The SilverMax 34HC-1 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. 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. In the context of the vehicle system integration, the use of such a motor system decreases complexity, increases reliability, and enhances performance.

5.4 Power System

In contrast to other vehicle designs, Gemini is powered exclusively by sealed lead acid AGM batteries. This safe and reliable power source provides the ability to operate Gemini in environments where a low acoustic signature and safety are paramount. Sole use of battery power eliminates the noise, fumes, and complexity associated with hybrid gasoline-electric power systems while demonstrating substantial single deployment runtimes. In addition, battery power in concert with brushless motor technology and solid state power electronics allows Gemini to be operated in hazardous environments where the possibility of igniting explosive material excludes internal combustion power sources.

As detailed in Figure 7, Gemini employs a simple battery system. This system utilizes eight Hawker Odyssey PC535 AGM sealed lead acid batteries. Each battery weighs 5.7 kg (12.5 lbs.) and provides 13 amp-hours of deep cycle capacity at 12 volts. When arranged into two battery banks these batteries provide 56 Amp-Hours of capacity at 24 volts. The power provided by the onboard batteries is distributed to the motors, computer, and sensors via the electrical box.

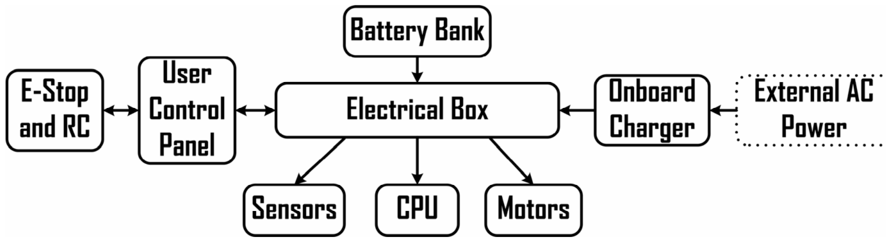

Figure 7: Power system schematic with each battery block representing two individual 12 VDC cells.

With the inclusion of an onboard charger, batteries need not be removed for recharging. By simply connecting a standard contractor grade extension cord to the weather proof rear power port, shown in Figure 8, the integrated Deltran BatteryTender charger can fully recharge the onboard batteries from an 80% depth of discharge in less than three hours.

Figure 8: Weatherproof AC power port used for recharging the onboard batteries.

5.5 Electrical Box

Figure 9 highlights the clean layout and space efficient design of the electrical box. The previous electrical design of Gemini proved to be exceptionally stable and resistant to failure during a full year of operation. However, several potential failure modes associated with the electro-mechanical relays and interconnects prompted an upgrade of the electrical distribution system in order to assure that the reliability of Gemini's power system would continue to be unrivaled. Upgrades to the distribution system adding to the overall system reliability include the use of solid state relays that are immune to vibration and wear, power conditioning capabilities to ensure reliable sensor operation, and a reduction in the number of physical interconnects.

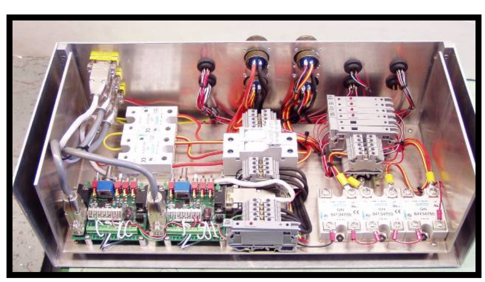

Figure 9: Updated solid state electrical box design with overall dimensions of 17" wide, 7.5" deep, and 8" tall.

5.6 System User Interface

User initialization of Gemini occurs via the user control panel conveniently mounted under the rear cover. The user control panel features main power switch and accessory power switches providing controlled application of power and a digital display of the current battery voltage. Gemini can be operated via a remote control transmitter that directly controls the motors and emergency stop independent of the onboard computer. This added functionality proves to be invaluable as it allows the vehicle to move under its own power during transport without the computer being powered on.

6. Sensors

Use of COTS hardware provides for a seamless integration of system components on Gemini. The advancement of commercially available sensors and networking solutions has simplified this traditionally complex and error prone enterprise. Also, it has afforded the use of smaller and more efficient components throughout the vehicle. The use of COTS sensors also eliminated the need for signal processing of raw sensor data as those functions are generally accomplished through sensor firmware. Gemini employs a suite of four COTS sensors that perceive the surrounding environment and supporting intelligent operation. The generalized system architecture is shown in Figure 10.

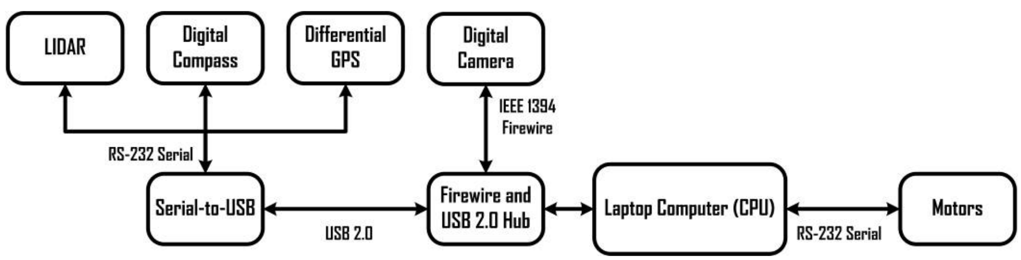

Figure 10: Diagram of sensor system architecture.

6.1 Digital Camera

Gemini utilizes a single inexpensive OEM Unibrain Fire-i board digital color CCD IEEE 1394 Firewire camera with a native 640 by 480 pixel resolution capable of an update rate of 15 frames per second (fps) and interfaces with the computer via an IEEE 1394 Firewire bus as shown in Figure 10. The housing is a custom designed weather resistant enclosure with an anti-glare filter to reduce the negative impact of reflective light on sensor exposure. The lens is a 2.1 millimeter fixed focal length lens that provides a 94° diagonal field of view.

6.2 Light Detection and Ranging (LIDAR)

Obstacle avoidance is carried out by means of mapping obstructions in the forward path of the vehicle via a SICK LMS-221 scanning laser rangefinder system and interfaces to the computer via a serial to USB converter as shown in Figure 10. The LIDAR scans a laser through a 180° planar sweep at a refresh rate of

15 Hz. The forward detection range of this scanner is 80 meters, but it is limited to only three meters during competition. The sensor is mounted on the front of the vehicle to provide an unobstructed view of potential obstacles with a 15° above horizontal orientation to prevent changes in gradient, such as a ramp or hill, from being detected as an obstacle.

6.3 Differential Global Positioning System (DGPS)

Vehicle localization is achieved by means of a Novatel ProPak-LB Differential Global Positioning System (DGPS) enabled with OmniStar HP correction service. The DGPS antenna is mounted at the top of the elevated instrumentation mast to optimize satellite signal reception. The Novatel DGPS unit provides vehicle location data and interfaces to the computer via the serial to USB converter as shown in Figure 10.

6.4 Digital 3-Axis Orientation Sensor

Vehicle heading is determined relative to the earth's magnetic field with Pacific Navigation Instruments TCM2-20 3-axis digital compass. The compass is mounted in a custom weather tight enclosure at the top of the instrumentation mast to reduce the adverse effect of electromagnetic and ferromagnetic sources. Additionally, the compass incorporates digital damping functions to minimize effects of vibration. As shown in Figure 10, the compass interfaces to the computer through the serial to USB converter.

7 Software

The National Instruments LabView 7.1 development environment is used to develop all software. The virtual instrument based programming naturally compliments the modular system architecture of Gemini.

7.1 Computer

The onboard CPU is a standard commercially available Sager NP8890 Pentium 4 class, 3.2 GHz notebook computer with one GB of RAM. The computer communicates with the sensors and motors by either RS-232 serial, USB, or an IEEE 1394 port. The operating system is Microsoft Windows XP Professional.

7.2 Software Operation

The intelligent navigation software that operates Gemini is preloaded on the onboard laptop prior to deployment. The user simply opens the program for the specific IGVC challenge that is to be run. The software provides feedback to verify that all systems are operational and optimal for navigation. Once all systems are online, the user presses "go" and the vehicle begins autonomous operation.

7.4 Autonomous Challenge Algorithm

The software developed to accomplish the Autonomous Challenge utilizes a digital Firewire camera for lane detection and LIDAR for obstacle avoidance. The algorithm combines the sensor inputs in order to generate the best forward path. The general approach for the autonomous challenge is detailed in Figure

11. The process cycles continuously during navigation, adjusting the vehicle heading and speed to effectively navigate the course until it is commanded to stop.

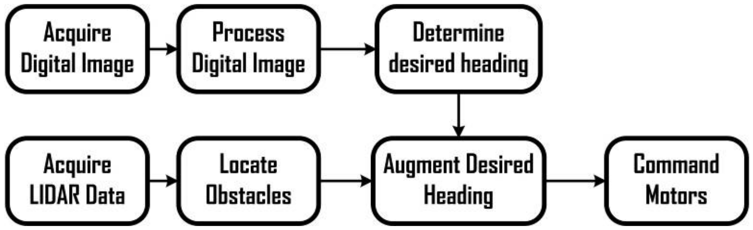

Figure 11: Autonomous Challenge Algorithm.

The image processing methodology is detailed in Figure 12. The acquired image is pre-processed by extracting specific image values from the composite RGB color image. To reduce processing time, the image is down sampled from the 640 by 480 pixel native camera resolution to 160 by 120 pixels and converted to grayscale. The area of the image including the vehicle is then removed and the image is then split in two, representing the view to the left and to the right of the vehicle. To determine the strongest linear relationship in the images, a Hough transform is used and the dominant line occurring in each half of the image is identified. This method works equally well for solid or dashed lines. A decision tree is implemented to determine a vehicle heading based upon situational line detection cases. The obstacle avoidance capability subsumes the vision derived heading. The final vehicle heading, being the composite of the vision and obstacle avoidance data, is then used to command the motors.

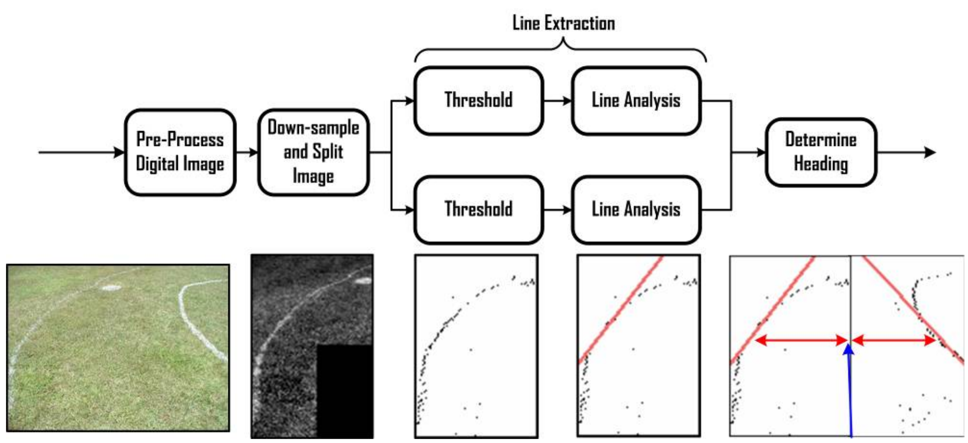

Figure 12: Image processing algorithm for boundary line extraction.

The final commanded path is represented as a curve yielding a fluid motion as the vehicle navigates the course. The use of curved path motor commands accounts for vehicle dynamics. While either a curved or straight path command assumes that the vehicle can instantaneously change velocity, the curved path accounts for the dynamic response of the commanded wheel speeds and more accurately renders the actual motion of the differentially steered vehicle.

7.5 Navigation Challenge Algorithm

The algorithm used to accomplish GPS based navigation uses sensory input from the DGPS, digital compass, and LIDAR and is described in Figure 13.

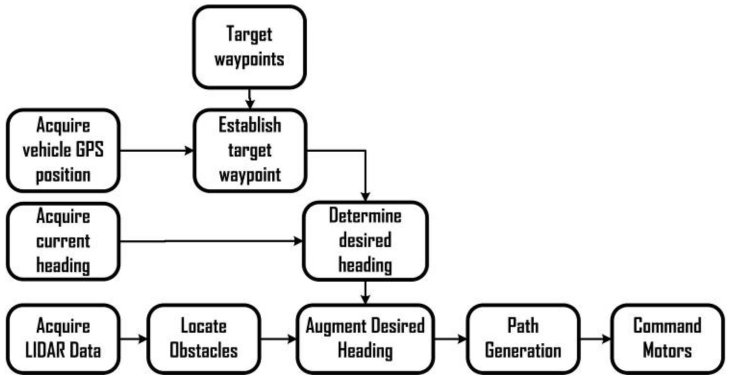

Figure 13: Overview of the Navigation challenge algorithm.

Path generation is derived from the known position and orientation of the vehicle and the next target position to which the vehicle is to achieve. A polynomial curve fit is used to plan a suitable path between waypoints. The LIDAR subsumes the GPS based heading and behaviorally conditions the vehicle desired heading until the obstacles are cleared and the vehicle can approach the target waypoint unhindered. When Gemini reaches the last target waypoint, it returns to the initial starting position and ceases motion indicating that the mission has been accomplished.

8 Predicted Vehicle Performance and Results

Vehicle performance has been assessed through practical application. Continued experimentation and the successful 2004 IGVC results support Gemini's intelligent capabilities and performance.

8.1 Speed

The Quicksilver brushless DC motors equipped with 10:1 reduction gearheads have a no-load output speed rating of 300 rotations per minute. Theoretically, 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 six to seven mph on a level surface. In competition, the integrated motor control software will enforce a strict five mph speed limit for both the autonomous and navigation challenges.

8.2 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 concrete inclines of nearly 40% grade (21.8 degrees). Additionally, Gemini is able to overcome abrupt discontinuities such as concrete curbs of more than four inches in height. Improved weight distribution favoring the forward drive wheels has bolstered these performance capabilities to include a variety of surfaces such as grass and bare earth.

8.3 Reaction Time

The process time of the vision software and the 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 68.1 ms. At a speed of five mph, this translates into the vehicle moving 0.1522 meters (0.5 feet) before the next navigation decision can be made. This reaction distance is well within the three meter (9.8 feet) forward detection range of the LIDAR and camera.

8.4 Runtime

Table 1 details the power requirements of all the components on the vehicle. A conservative estimate of the over all power consumption is determined based upon published maximum specifications and supported by experimental results. Values presented in the table are based upon the nominal power consumption experienced during autonomous operation through a standard IGVC type autonomous challenge course with all vehicle sensors operating and an average forward velocity of two mph.

Table 1: Estimate of Power Consumption.

Component (Nominal Operating Voltage)	Current (Amps)	Power (watts)
Quicksilver 34HC-1 Brushless DC Servo Motors (24 VDC)	3	72
Sager NP8890 Pentium 4 Laptop Computer with screen on standby (20 VDC)	2.5	50
Unibrain Firewire Digital Camera (12 VDC)	.075	0.9
SICK LMS-221 Scanning Laser Range Finder (24 VDC)	1.8	43.2
Novatel ProPak-LB Differential GPS (12 VDC)	0.4	4.8
PNI TCM2-20 3-Axis Digital Compass (12 VDC)	0.02	0.24
Remote Control and Emergency Stop (12 VDC)	0.75	9
DLink 802.11b/g Wireless Router (5 VDC)	1.25	6.25
DLink DFB-7 USB 2.0 and Firewire Hub (5 VDC)	0.8	4
Lascar electronics Panel Mount Voltmeter (24 VDC)	0.003	0.072
Totals	**10.6 Amps**	**190.5 watts**

Based upon the data presented in Table 1, a conservative estimate of Gemini's fully autonomous runtime is approximately five hours. Maximum runtime can be augmented by the implementation of alternative power usage schemes. Additionally, experimental results suggest that Gemini can be operated in RC mode for nearly 20 hours. All onboard batteries can be recharged in less than three hours.

8.5 Obstacle Detection Distance

The scanning laser rangefinder has a range of 80 meters (262.5 feet), but the current navigation software ignores obstacles that are further than three meters (9.84 feet) 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 one to 2.5 meters (3.28 to 8.20 feet) in front of the vehicle.

8.6 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 and augment the forward heading to avoid obstacles. Effective obstacle detection and path planning generally result in dead ends and trap being avoided however, if the vehicle encounters a dead end, the vehicle performs a near zero radius turn until a suitable path is found. Gemini also has the unique ability to use GPS location data to determine if the vehicle has reversed itself around the course as a result of a dead end or trap. Knowing this, the vehicle can reorient itself on the course to complete the mission.

8.7 Accuracy of Waypoint Navigation

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. The GPS unit runs at a 20 Hz sample rate, which provides a significant advantage during high speed GPS navigation.

8.8 Accuracy of Headway and Lateral Deviation Maintenance

The digital compass used on Gemini displays a ± 0.5° to ± 1° 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.

9 Testing and Simulation

The Autonomous Vehicle Team simulator is a library of software that constructs a virtual world with simulated lines, obstacles, and waypoints. The general scheme of the software simulator is presented in Figure 14. Within the simulation software, users can monitor simulated sensor data, vehicle response, and a global map of the constructed virtual world.

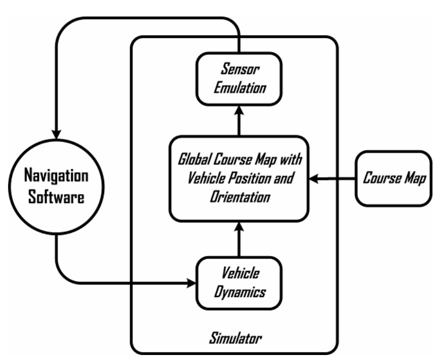

Figure 14: Diagram of the software simulation environment.

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. It is notable that the overall system cost can be reduced through the use of less accurate sensor technology and through the maturation of the sensor technology driving the cost for sensor technology down.

Table 2: Summary of vehicle component costs.

Components	Retail Cost	Cost to Team
Sager NP8990 Laptop	$2,435	$0
(2) QuickSilver DC Brushless Motors	$2,450	$2,450
(8) Hawker PC 535 AGM Dry Cell Lead Acid Batteries	$640	$640
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	$495	$0
DLink Wireless AirG 802.11g router	$99	$99
DLink DFB-7 USB and Firewire Hub	$60	$60
Electrical Components	$700	$700
Aluminum Frame and other frame materials	$400	$400
(4) Low Rolling Resistance Composite Nylon Wheels	$75	$75
Igus IP68 Flexible Wire Conduit	$150	$0
Total	**$22,221**	**$13,431**

11 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 13th annual IGVC.