

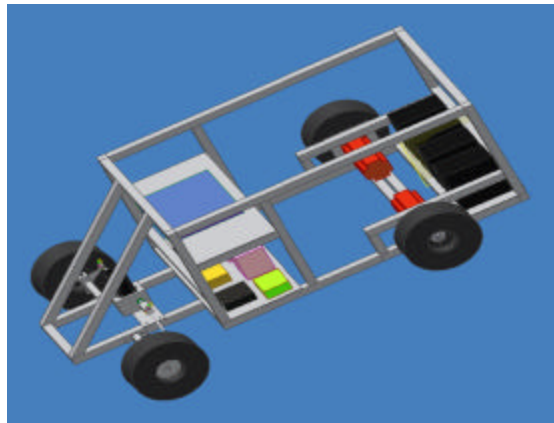
TNA

(Terrain Navigation Automated)

Stony Brook Robot Design Team

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Stony Brook University



Team Members

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Faculty Advisor Statement

I certify that the engineering design of the vehicle described in this report, TNA, has been significant and is equivalent to the work load of the six credit full year senior design projects.

5/22/2007

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Date

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1 Introduction

The Stony Brook Robot Design Team of Stony Brook University is proud to present TNA (Terrestrial Navigation Automated), the end result of a collaborative effort among computer science, electrical engineering, mechanical engineering and physics undergraduate students. This autonomous vehicle is designed exclusively for participation in the 15th Annual Intelligent Ground Vehicle Competition (IGVC). TNA is a single body, four-wheeled vehicle with smaller tires on the front end. The design characteristics include two independent drive motors (QuickSilver 34HC-3) on the rear end of the vehicle in order to optimize steering capability as well as traversing “rough” terrain more effectively. There is also another independent, smaller motor for the front end, allowing for four wheel steering capabilities, an electrical power distribution system, a LIDAR / camera system for navigation with the DGPS, and an operator control unit with a mechanical and a wireless emergency stop. The system’s intelligence is controlled by an onboard laptop computer.

2 Innovations

Several innovations were incorporated into the design of this system. The first is the use of a wireless car alarm system providing a simple and cost effective way to provide the vehicle operator to stop the vehicle in emergencies. The second innovation is the use of a two independent steering systems. The front wheels are steered by one motor via connection of the two front wheels with a solid linkage. The rear wheels provide additional steering capability due to the use of two independent motors, which drive the two rear wheels separately. This provides the vehicle with maximum maneuverability and reduces the turning radius to a minimum.

3 Design Process

3.1 Problem Definition

The rules of the IGVC were read by each team member and were then discussed at a full team meeting. This meeting began with discussions of the design limitations based on the criteria of the competition. These discussions lead to a brainstorming session on conceptual designs.

3.2 Team Organization

The team consisted of an executive board that handled the administrative tasks of the team including fundraising and communications with the various departments within the university. This

organization is shown in Figure 1.

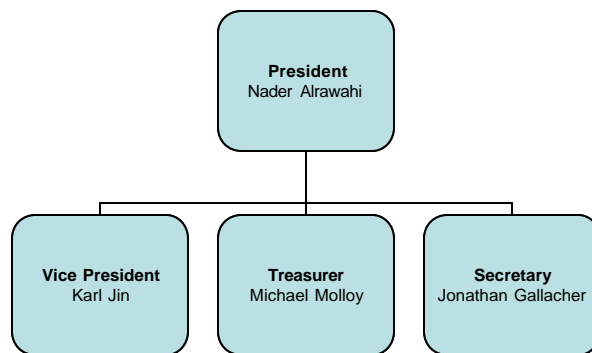


Figure 1. Team Executive Board Organization

The team was also organized into several design teams to allow individual members to specialize in certain subsystems or components. The team consisted entirely of undergraduate students and was run as a student organization. The team was lead by the team president who was supported by the CS/EE Team Leader and the ME team leader. The team structure is shown in detail in Figure 2

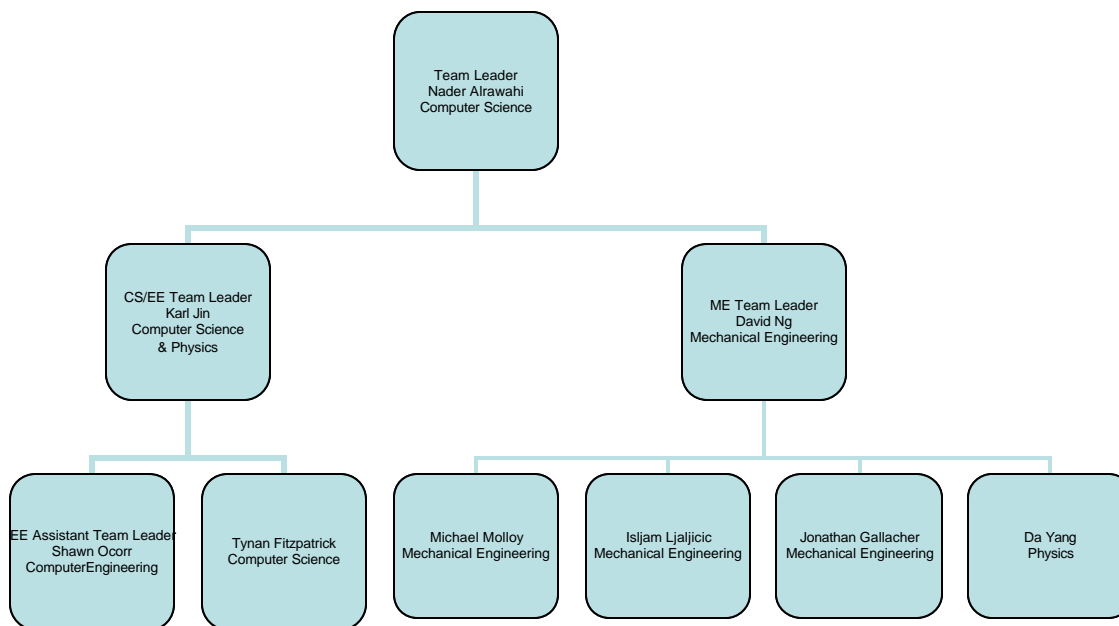


Figure 2. Complete Team Organizational Structure

3.3 Conceptual Design

A thorough understanding of the rules led to a discussion of desired size of the vehicle, type of vehicle and power source. The vehicle size was set at an arbitrary size based on the minimum size requirements set by the rules and consideration of stability of the vehicle over rough terrain. The power sources suggested as possibilities included batteries, fuel cells, gasoline powered engine. The group decided that batteries offered the best combination of cost, ease of use, reliability and safety for this project.

The discussions on the type of vehicle focused primarily on how many wheels, wheel placement, and number of driving motors. The top suggestions were use of tank-like treads instead of wheels, three-wheeled vehicles, or four-wheeled vehicles. The tank-like treads were the most popular, however research showed a lack of availability of parts for a vehicle in this size range. This lack of COTS components for the tank design leads to the choice of a four-wheeled vehicle. The top suggestions for how to steer and drive the vehicle were to have steering with the front and a solid rear wheel drive or to have independently powered rear wheels with front casters. There was considerable discussion on these two designs and in the interest of minimizing cost the first choice with a rear wheel drive with a single motor and front wheel steering with one motor was chosen. There was also discussion about the types of sensors need to compete in both active events. A list of needed sensors was created at this meeting and during the following few weeks as the team gained knowledge in how to best use current sensor technology for the tasks required by the competition rules.

3.4 Detailed Design

The selection of the final conceptual design leads into the detailed design process. This initially entailed two major areas. The first was the frame design and the second was major component selection. As the final detailed design would need to take into account the purchased components the process of searching for and selecting motors, LIDAR, cameras, GPS, wireless emergency stop, batteries, wheels, motors, and computer controller.

3.4.1 Major Component Selection

The task of selecting major components was broken up and assigned to members based on their area of expertise. The mechanical engineering students focused on selecting the batteries, wheels and motors. The computer science students focused on sourcing the LIDAR, cameras, GPS and wireless emergency stop. The team decided that it would be easiest and cost effective to use the Dell laptop already owned by the team as the main system controller.

3.4.2 Original Design

A rough 3-D model of the original design is shown in Figure 3. This design incorporates representations for the selected Quicksilver motors and the expected mounting and additional system components needed for the drive and steering systems. This design was presented to the team to discuss

possible problems and potential improvements. The design utilized extruded aluminum frame elements and matching connecting hardware as is available from Bosch. The connection of the motors required numerous additional custom machined parts made from sheet aluminum. There were also a number of bearings required to support the rear drive shaft. The estimated weight of the vehicle was approximately 200 lbs.

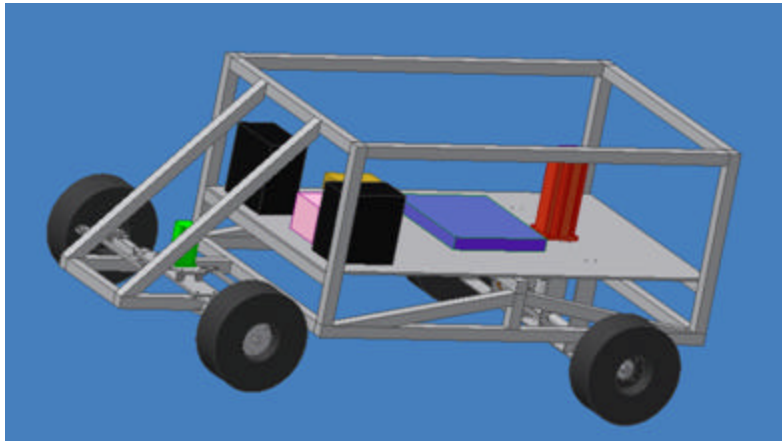


Figure 3. 3-D Model of Original Conceptual Design

3.4.3 Revised Final Design

It was agreed that the rear drive system should utilize two motors so that each rear wheel could be controlled independently. This would provide better steering control, especially when maneuvering tight turns. There was also agreement that the design required far too many custom parts and that a redesign to decrease the number of parts and manufacturing time be done. The mechanical team discussed the best way to incorporate the additional motor and reduce the large number of custom parts. This resulted in a drastic redesign as is shown in Figure 4. Please note that this 3-D model is missing the sensor mounts as the models of these subsystems weren't created in time for this paper.

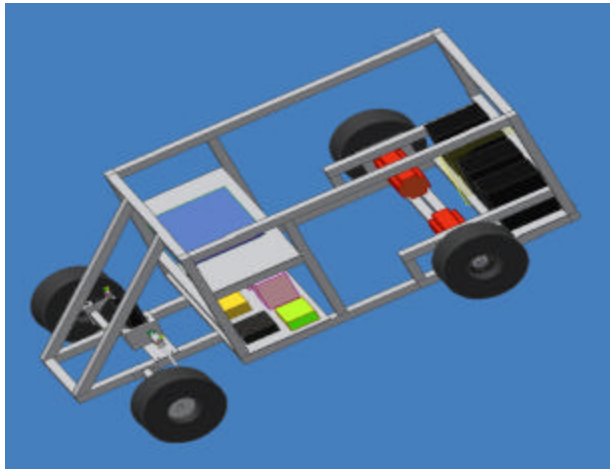


Figure 4. 3-D Model of Final Detailed Design of TNA

3.5 Manufacturing & Assembly

The detailed design shown in Figure 4 doesn't include the completed front steering assembly of the sensor mounts. This is due to the desire to manufacture the frame and rear drive subsystem first and then complete designs and manufacturing for the remaining systems. Many of the remaining systems were designed completely on paper using measurements from the model pictured above as a base and allowing us to account for items overlooked when completing the original CAD work.

3.5.1 Frame Construction

The frame of the robot was designed to be large enough to ensure adequate space for all system components. The overall dimensions of the frame are 60.3" X 26.4" X 19.0" (L X W X H) with the rear area containing the rear drive system, electronics, and laptop measuring 42" X 26.4" X 19.0". The frame consists of 30mm X 30mm Bosch extruded aluminum and is assembled using gussets, and angle joints to provide a sturdy and impact resistant frame.

3.5.2 Actuator Mountings

There are three computer-controlled QuickSilver motors. The smaller QuickSilver H5 is used in combination with the SilverDust IGB motor controller to actuate a front rack and pinion steering linkage. The other two actuators are QuickSilver 34-HC-3 motors used in combination with individual SilverNugget N3 motor controllers. These two motors drive the left and right rear wheels independently providing the driving power of vehicle while adding additional steering capabilities.

3.5.3 Sensor Mountings

There are sensor mountings for the LIDAR, cameras, and GPS systems. The LIDAR is a SICK

LMS 221 and is mounted first on a bracket purchased from SICK. This bracket was then mounted to a 12 1/8" long piece of 30mm X 30mm extruded aluminum. This bar of extruded aluminum was mounted to the angle frame pieces on the front of the vehicle using angle connectors. This mounting system allows the height of the LIDAR from the ground to be adjusted and the angle the front face of LIDAR has with the ground can also be adjusted.

The GPS system was mounted on an extruded aluminum tower with a custom mounting plate attached to the GPS to facilitate attachment to the extruded aluminum.

The camera mounts for the three cameras are adjustable to allow for testing and realignment and are primarily made of wood to provide some vibration absorption. These wooden mounts are attached directly to the extruded aluminum frame.

3.5.4 System Enclosure & Water Proofing

This vehicle is designed for outdoors use and must be able to operate during stormy weather. This required the use of polycarbonate panels to shield the electronics and some of the moving parts from rain and other debris. This allows the design of the vehicle to be easily seen, problems to be more easily diagnosed, and easy access to internal system components for repair and modification.

4. Major Vehicle Subsystems

This section will be used to describe the design of the major vehicle subsystems.

4.1. Rear Drive Subsystem

The drive subsystem of TNA consists of two independent motors (QuickSilver 34HC-3). Each of them is mounted on extruded aluminum beams and connected directly to a wheel hub. The speed and direction of each wheel can be controlled by controlling the voltage sent to each motor. A schematic of the rear drive subsystem is shown in Figure 5 below.

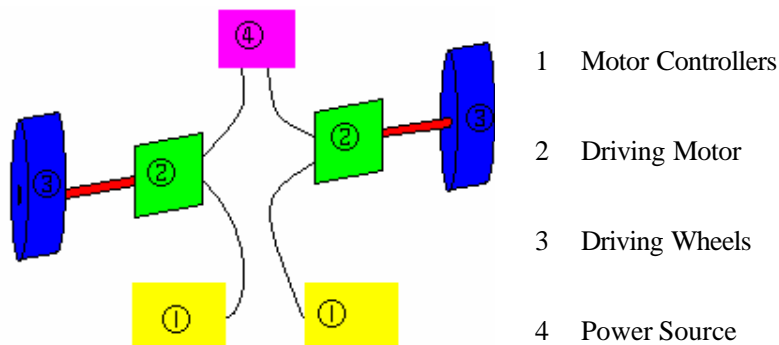


Figure 5. Schematic of Rear Wheel Drive Subsystem

4.2 Steering Subsystem

The steering control system of the robot was designed by implementing a medium sized stepper motor to provide the necessary power for quick maneuvering. The motor was coupled to an adapter that would allow for a custom designed rack & pinion system to be implemented with clevises to allow for easy calibration, fabrication, and overall system robustness during use.

Calibration objectives are met by adjusting the rod end length and clevis position on the length of the rack. As a result the system is capable of providing full adjustability so that the wheels can track perfectly going in a straight line and in a turn.

The system is designed to have a high degree of modularity, to allow parts to be easily fabricated, so that there would be a large number of simple parts to produce rather than a small number of very complex parts. This is in following the logic that very complex parts have a tendency to be less proven in the field whereas a system composed of a clever assemblage of familiar simple components would be robust, and in the case of a failure, they could be easily replaced. Of course, because the rack & pinion is a custom component, it was unable to meet this demand and required extensive analysis to be implemented. The remaining subsystem components were simple enough that spare parts can be easily made in a short time.

To provide overall system robustness, the rack and pinion system was designed with aluminum and steel components for sturdy construction as well as incorporating a design that ensures the motor's output force is optimized to the low speed high torque situation.

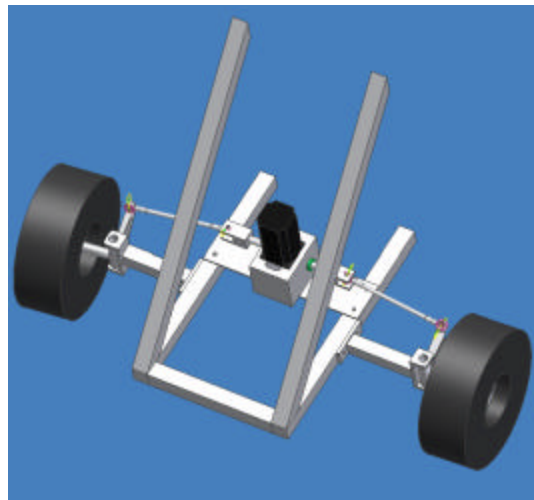


Figure 6. 3-D Model of Front End Steering Subsystem

4.3 Electrical Power Distribution Subsystem

The electrical system of our robot is composed of the following components:

1. LIDAR
2. GPS
3. 3 Webcams
4. Motor-controllers (3; 1 for each back wheel, and 1 for the steering column)
5. 3 Motors (2 with voltage clamps and resistor packs)

The custom electrical design itself is simple; as the innovations for the robot are mostly in the mechanical design and software strategy. The innovations in the electrical design is in the converted use of inexpensive components originally designed for different purposes. All of the devices listed above are connected to 12V lead acid batteries, with appropriate uses of fuses to protect the devices in the case of a current surge. The motor-controllers are connected to separate batteries. Separating the drive motors from the data-acquisition devices is necessary to maintain stability of the system and prevent large current fluctuations in the sensors. In addition, an emergency shutdown system has also been implemented, which cuts off the battery to all devices when activated.

4.4 Sensors

The vehicle has three main sensors to provide the necessary vision, obstacle detection and navigation data for successful and efficient course navigation. This consists of a LIDAR (SICK LMS 221), three cameras (Logitech Quickcam Pro 5000), and GPS (Raven Invicta 115).

4.4.1 LIDAR

To aid in the navigation process, we used a LIDAR device, specifically the SICK LMS221 shown in Figure 7. This device sweeps 180° (or 100°) on a single plane and returns values indicating distance to the nearest target. Multiple settings for the device allowed determination of a balance between precision and the time taken to perform a single sweep. These settings are:

0.25° intervals, 100° range → 401 data values

0.5° intervals, 100° range → 201 data values

1° intervals, 100° range → 101 data values

0.5° intervals, 180° range → 361 data values

1° intervals, 180° range → 181 data values



Figure 7. Picture of SICK LMS 221 LIDAR

The optimal LIDAR setting for this competition was scanning at 1° intervals over a 180° range. A range of 180° was necessary for our robot, and a 1° interval was determined to be precise enough for successful object detection.

4.4.2 Cameras

While the robot heavily relies on information from the LIDAR system for obstacle detection and avoidance, there are objects not identifiable by the LIDAR system. Therefore, three Logitech Quickcam Pro 5000 cameras are also installed on the robot. These are installed at fixed locations with fixed angles and therefore fixed views. They are placed so that they will provide a field of view covering the front 180° of the robot up to a distance of six meters. The cameras use USB channels to interface with the computer.

4.4.3 GPS

The navigation system is fed information by the Raven Invicta 115 GPS receiver, which interfaces with the computer using a serial-to-USB converter. This system sends NMEA compliant data to the computer for further processing.

4.5. Safety Systems

The vehicle required three safety components to be in compliance with the IGVC rules. These components on the onboard system kill switch, the wireless remote system kill switch, and the system speed limiter.

4.5.1 Onboard System Kill Switch

The system can be turned off in an emergency by pressing down the large 1.5" diameter red button located on the top surface of the vehicle at the center of the rear end. This switch disables computer controls and allows the vehicle to come to a complete stop.

4.5.2 Wireless System Kill Switch

The wireless remote emergency shut off system consists of a Commando EZ-2500 Remote Starter with keyless entry system. This completes the same shut down action as the onboard system switch. This wireless safety system has a maximum range of one thousand feet.

4.5.3 System Speed Limiter

The system is required to be limited to no more than 5 mph. This is accomplished by use of voltage and current limiters, which limit the maximum power that can be sent to the drive motors.

5 Software & Vehicle Artificial Intelligence

5.1 Overall System Software Design

The software is constructed using C# in Microsoft Visual Studio 2005, chosen for its native support of COM devices as well as image rendering using DirectX. In addition, near-direct access to existing libraries in C or C++, which makes integration of different systems a lot easier, can be achieved through .NET CLR platform. The software was designed with an emphasis on modularity and low coupling between software components with specific interfaces between modules, highly utilizing the Objected Oriented Programming concept. This is highly desirable for a team-based development environment.

Hardware-specific code was contained within its own class, so that a decision to replace any of the sensors or the motion controls would not affect the main Artificial Intelligence or other modules. In addition, the modules designed to interface with the various robot components could be replaced by virtual components, so that the robot can be run inside a simulator for the purpose of testing the navigation algorithm under ideal circumstances. This helps the parallel development of the mechanical system and the navigation algorithm.

5.2 Motion (Motor) Controllers

The motors all utilize the same infrastructure which is the proprietary protocols of QuickSilver Controls. The primary means of controlling the robot's path involve VMI, which allows the robot to change velocities, start, or stop at any point. While the software would need to be configured to use motor controllers that did not use that protocol, it does have the advantage that any of QuickSilver's motors can be

substituted for the current motors without need for any modification to the source code. In addition, the drive and steering subsystems could be replaced in their entirety and the software can be easily redesigned and quickly redeployed if the hardware configuration was heavily modified. The desire to maintain principles of information hiding required the core components of the code to be dependent only on the drive and steering subsystems interface. This principle can be adhered to as long as the role of each motor in the drive and steering subsystems can be described in a clear manner.

5.3 Obstacle Detection and Avoidance – LIDAR Data Acquisition

The obstacle detection is achieved by use of the LIDAR. When writing the program to communicate, through serial connection, with the LIDAR, there were a few problems. The basic communication process for using the LIDAR is as follows:

1. A command (some example commands are listed below) is sent to the LIDAR

Examples: Start Transmission OR Stop Transmission OR Enable Settings

2. A reply command is sent back to the computer

The manual for the LIDAR contained all the send and reply commands, however; all of the reply commands contained small errors. Fortunately, all of the send commands were correct, and a decent amount of time was spent sending a command to the LIDAR and comparing the actual reply command with the given reply command. Eventually, after a little trial and error, all reply commands were verified.

Other than the manual's erroneous reply commands, the setup of the communication between the LIDAR and the written program (which was programmed in C#) went very smoothly.

The robot must analyze its distance from objects that are at its immediate left and right. Further details of this algorithm will be explained later. In addition to the "sweep" settings of 1° intervals over a 180° range, the LIDAR also has distance settings with a choice of millimeter (mm) or centimeter (cm) mode. The data values returned by the sweep range from 0 to 8191; and if the current mode is mm, the max distance that can be "seen" by the LIDAR is 8191 mm, or about 8 m. In cm mode the max distance is about 80 m. Since the field itself is rather large, and there is no need to be accurate to the nearest millimeter, it was decided that the cm mode would be most efficient for this competition.

5.4 Camera System Data Acquisition & Processing

The images received from the three cameras are processed by DirectX system for speed acceleration. The main image processing is done to detect lanes and visually identifiable obstacles. First, a color filter is applied to identify colored lanes and cones, for which the colors are stated in the competition rules. Edge detection and pattern recognition are then applied to find other items on the camera view such as potholes.

5.5 Information Merger

To increase modularity even further, it is decided that the core AI system will be fed with only one format of sensory data. This means that the information from the LIDAR system and the camera system must be merged into one data format. This is done by converting data from the camera system into the LIDAR format and merging them together.

Since the positions and angles of the cameras are fixed and known, once color-filtered and edges are detected, dots on the 2D views of the cameras can be converted into an angle-direction vector format relatively easily through simple geometry. For any given angle the closest item observed by any of the four sensors (LIDAR and three cameras) is selected to represent the open space for that angle.

5.6 Global Positioning System Data Acquisition

While the software was designed utilizing the Raven Invicta 115 GPS, the code is interoperable with any NMEA-compliant device. The benefit of using the NMEA standard is that any device that uses that standard can be substituted for that device, allowing the client to make the final decision on the device used, depending on either a certain degree of precision that needs to be met or a budgetary cap that needs to be cleared. In addition, this sub-system also keeps track of waypoints and therefore separates the entire functionality of finding where to go in terms of direction. This helps the driver component of the system to focus on how to detect and avoid obstacles in order to drive to the desired direction, and if the positioning system is changed, i.e. GPS to an in-building positioning system, only the navigation component will need to be changed and the driver component will stay untouched.

5.7 Artificial Intelligence (AI)

The AI system is the core system that decides what signals send to the motors, effectively controlling the entire motion sequence of the robot. First, it is fed with information from the merger system.

The merger process takes raw data from all sensors and converts the multiple data one merged data format as shown in Figure 8. This data stream contains information on how much open space the robot has for each angle for the front 180 degrees.

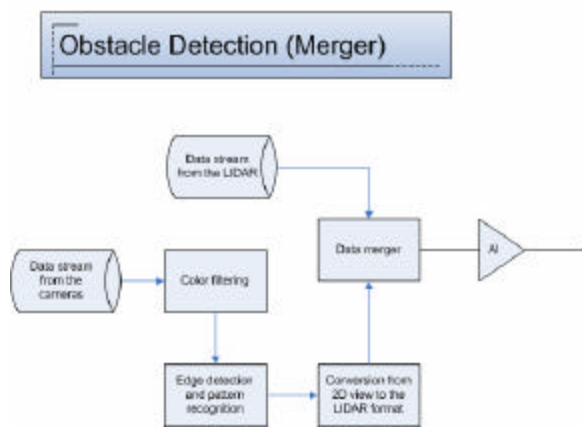


Figure 8.
Flow Chart for Data Acquisition and Merger

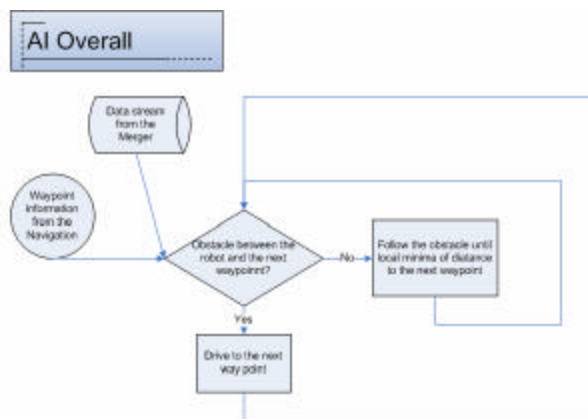


Figure 9.
Flow Chart for Artificial Intelligence

The artificial intelligence algorithm was difficult for the team to finalize. This algorithm is designed to work for both the autonomous challenge and the navigation challenge. The basic navigation process is as follows:

1. Robot turns to face the goal (using the GPS)
2. Robot moves forward until the space in front of it is not clear (not clear has default value = 3m)
3. Robot follows the wall to the right until it passes a local minimum distance to the goal (again using the GPS)
4. Repeat

Some members thought step 3 inefficient, claiming there might be a better decision making process, one that would make a decision based on the angle to the goal. This idea was discussed and debated, and in the end it was decided that, though our final algorithm may not be the most efficient in theory; it would be accurate and would not cause an infinite loop. The main portion of the coding, which was done in C# again, occurs in step 3. The idea is to keep the robot at a constant distance from the wall while still following the wall. Using trigonometry we were able to accomplish this. The program analyzes the ten left most values in the sweep (array values 172 through 181), considering this the robot's left; and does the same for the robot's right and front. These ten values are then put into a class that performs statistical analysis; such as mean, variance, etc. In addition, we have a class that performs dual set statistical analysis; which calculates

covariance, and correlation. Using this calculated data we can get a good representation of the shape of the wall, or object, and therefore how much to turn to continue following the wall, or avoid the object. Originally, the calculations were going to revolve around derivatives and averages, however; it was decided that incorporating statistical analysis would make for a more accurate representation of the robot's surroundings.

Once the AI system decides the ideal next course of action, it sends somewhat abstract commands, such as to go forward for a given time or to turn left for a given angle, to the motor controller system, which will then interpret these commands and send appropriate lower level commands to each motor under its control. This again helps with modularization and improves reaction response to changing conditions and allows the AI to be used with different mechanical designs for the robot.

6 Predicted Performance

6.1 Maximum Speed

The drive wheels are ten inch in diameter and considering the optimal angular speed and torque of the 34-HC-3 motors, the maximum speed with no losses and on level ground is 29.8 mph. The actual maximum speed has not yet been determined experimentally but will be limited for the competition to 5 mph.

6.2 Other Performance Items

The performance of the system for the following parameters had not been determined by the deadline for this paper. These metrics include system run time or battery life, ramp climbing ability, obstacle detection distance and how accurately the system can reach waypoints. The expected maximum obstacle detection distance is about 8m based on the limitations imposed by the LIDAR. The GPS has a RMS accuracy of less than 1m when using differential correction signals and while the system has line of sight connection with five satellites.

7 Vehicle Cost

Included here is a breakdown of the purchased components used in construction of TNA. This doesn't include custom manufactured parts.

Component	Quantity	Cost		Component	Quantity	Cost
SICK LMS 221 LIDAR	1	\$5,421.43		LIDAR mounting bracket	1	\$ 76.50
QuickSilver 34-HC-3	2	\$1,467.30		Wireless transmitter - Commando EZ-2500	1	\$ 69.99
Raven Invicta 115 GPS	1	\$1,359.00		Breakout modules for 34- HC-3	2	\$ 43.55
Dell Inspiron Laptop	1	\$1,200.00		Spindle and Brackets for Front End	2	\$ 33.98
SilverNugget N3 Motor Controllers	2	\$ 777.60		Electronic Components		\$ 30.26
Extruded Aluminum and connectors		\$ 739.64		Breakout module for 23-5	1	\$ 21.44
Motor Cables	7	\$ 472.35		Front Wheel Tires	2	\$ 20.30
SilverDust IGB D2 Motor Controller	1	\$ 408.00		Wire		\$ 19.95
Logitech Quickcam Pro 5000 Webcams	3	\$ 259.80		Front Wheels	2	\$ 19.30
Voltage Clamp	2	\$ 227.80		Rod End Bearing	4	\$ 12.36
QuickSilver 23-5 Motor	1	\$ 221.10		4 port USB hub	1	\$ 11.99
Hawker Odyssey PC 625 Lead Acid Battery	2	\$ 143.90		Screws		\$ 10.00
Polycarbonate 1/16" thick	1	\$ 122.80		Serial port to USB port cable	1	\$ 8.99
Resistor Pack	2	\$ 107.20		Bearings	4	\$ 6.36
Rear Wheels	2	\$ 94.00		Red 1.5" Diameter Emergency Button	1	\$ 6.10
Rear Hubs	2	\$ 80.00			TOTAL	\$13,492.99

8 Conclusion

TNA represents the most complex robot ever built by the Stony Brook design team based on the large number and type of sensors used in this design compared to previous robotic systems built by the team. The final design represents a process of simplification designed to reduce cost, complexity, and manufacturing time. It also represents improvements in stability, overall weight reduction, and ease of maintenance, troubleshooting and modification. TNA is expected to be competitive at the 15th Annual IGVC and we thank everyone who has dedicated their time, effort, and resources to setting up and running this event.