Stony Brook University

TINA
(Terrain Independent Navigation Autonoton)

Intelligent Ground Vehicle Competition 2009

Team Members

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Faculty Advisor Statement

I certify that the design and creation of TINA has been significant and is equivalent to what might be awarded credit in a senior design course.

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Department of Mechanical Engineering at the University of Stony Brook

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Date

1. Introduction

The Robot Design Team of Stony Brook University is proud to present TINA (Terrain Independent Navigation Autonoton) for the 2009 IGVC competition. This autonomous robot is the end result of a collaborative effort of undergraduate students whose majors consist of computer science, Mechanical Engineering, and physics. The design behind TINA consisted of taking advantage of the best features from our previous robot from 2007, TNA, as well as incorporating new features. After a careful evaluation of TNA, we came to the conclusion that these new features were necessary in order to correct the mistakes that were made then.

2. Innovations

One innovation implemented was a single steering system. With such a system, the robot can turn about its center. This way, a zero turning radius will be possible for maximum maneuverability. To govern the speed of the robot, two speed reducers were selected such that they could be used with our two motors. Therefore, the speed reducers actually serve two functions. The first function is turning assistance and the second function is for speed governing.

Another innovation was the wireless e-stop. It was decided to use a wireless car alarm system. This provided a simple and inexpensive way for fulfilling this stipulation in the IGVC rules. Aside from the emergency switch that is required, TINA is also equipped with an on/off kill switch for added safety. A camera algorithm was also made using C #. The significance of this program is that it can be used on any camera and not just the ones TINA will be using. The electronic circuitry is also easily accessible because of the door hinge mechanism that was installed. So if there is a problem that needs to be diagnosed, we just simply flip up the door itself.

3. Design of TINA

3.1 Team Structure

Before developing conceptual designs, it was first necessary to have some organization. The team was organized into two sub-teams. This allowed individual members to belong to one or the other according to one’s skills and talents. The two sub-teams are the Computer Science/Electrical Engineering sub-team and Mechanical Engineering sub-team. As their name imply, each sub-team would develop certain subsystems that are within the scope each respective sub-team. The leader of both teams was the president and each sub-team had its own respective leader. The two sub-team leaders would then report to the president any progress and/or setbacks that occurred.

3.2 Conceptual Design Phase

Since this team has participated in this event before and that major stipulations in the rules have not changed, such as dimensions and navigation objectives, the team’s conceptual ideas were based on the desirable features of TNA as mentioned earlier. In effect, this had simplified the thought process when brainstorming ideas. Originally, the basic frame of the robot itself was supposed to be a frustum for aesthetic purposes. However, since it was decided to use the extruded aluminum, which was the way TNA was made, the construction of a frustum would have meant the use of additional complex fixtures. The extruded aluminum seems to be best for joining two (or more) pieces perpendicularly and not on an angle relative to each other. Ruling the frustum idea out, the next idea was to make a simple rectangle that can easily turn. Playing with this idea, the final concept can be seen in Figure 1 below.

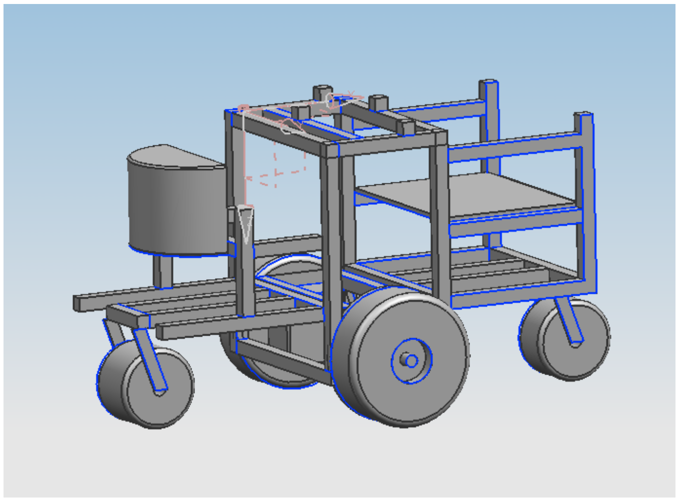

Figure 1: Final Design Concept

3.3 Detailed Design Phase

3.3.1 Mechanical Design

One of the first concerns the team had was maneuverability. In the competition back in 2007, TNA had two independent steering systems. Ideally this seemed like the best solution, but during the competition, it did not suffice. The rack and pinion steering system did not turn the robot as much as we needed it to. To get around this problem it was decided that a single steering system was to be implemented instead in order to eliminate the complications from the previous design. This steering system consists of two drive motors in the middle, which are governed by speed reduced as mentioned earlier. The speed reducers have a 10:1 gear ratio, which meets our criteria to be within the 5 MPH speed limit. Turning would be performed by having one wheel turn forward, while the other wheel would turn backwards. For support, one pneumatic castor would be mounted in the front center and another in the back center. As mentioned in the conceptual design phase, aluminum extrusion would be used for the frame since it is durable, lightweight, inexpensive, and assembly is relatively easy because of the available fixtures made specifically for this type of building material. If something mechanically wrong occurs during testing, for example, the frame can be easily taken apart and proper modifications can be made. The chassis contains the batteries as being used as the power supply, the laptop, which is the main system controller, the electronic circuitry, the sensors and the emergency stop (pushbutton and wireless). Mounted on top of the robot is an aluminum extruded structure that accommodates the payload. In effect, this allows easy access to it. For weather proofing, polycarbonate sheets of a thickness of 1/16 of an inch will be used since it is easy to mount them on the robot. In order for the wheel to be mounted to the motors, an aluminum hub was designed with a key-way. A CAD drawing of this hub can be seen in Figure 2 below.

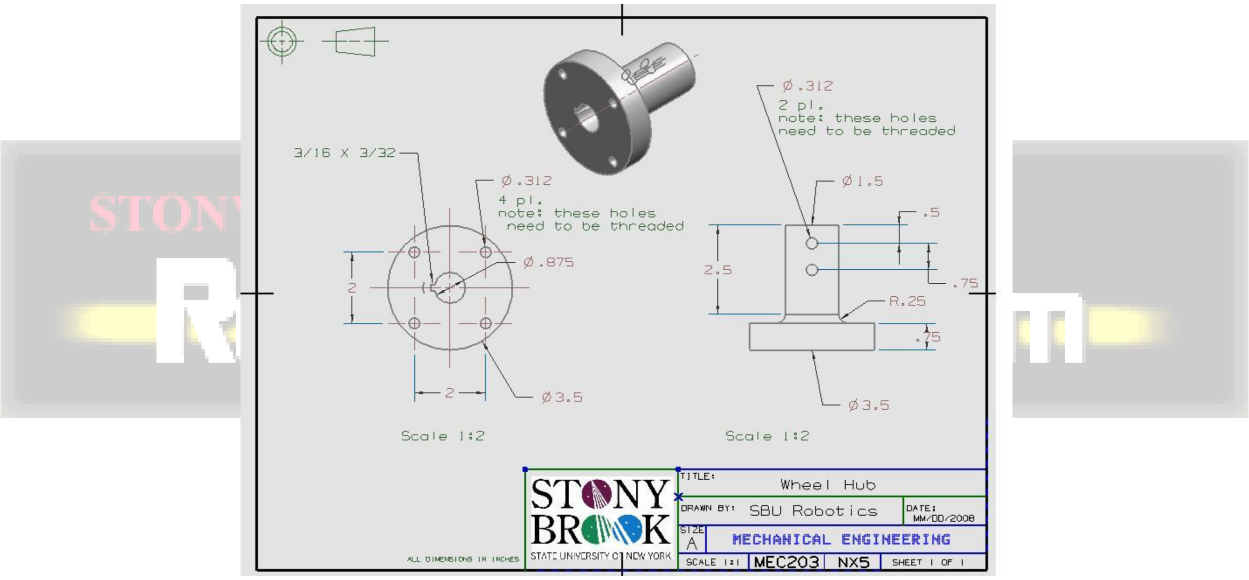

Figure 2: CAD drawing of wheel hub assembly.

3.3.2 Electrical Design

The power source of TINA will be two lead acid car batteries connected in series. This is so that 24 volts can be supplied to the motors, which draw about 32 amps overall. These batteries supply power to all the sensors and motor controllers. All of our electrical components run on 24 volts, so this eliminates the need for a dc/dc converter to 12 volts. As far as the cameras go, they are just simply powered by the laptop. It was decided that the majority of the electrical components that were used on TNA were to be used on TINA. There was no point in spending additional money on components that are functional. The only motor that is not being used is the QuickSilver H-5 along with the SilverDust IGB controller since they were used for the rack and pinion steering in TNA. For safety purposes, the majority of the electrical components, including each motor, will each have its own designated 20 amp fuse. For wire neatness and to avoid “rat nests”, barrier strips will be used for the electric circuits as well.

3.3.3 Motor Controllers

TINA uses two SilverNugget N3 motor controllers that are made by Quicksilver. The motors themselves 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. For our motors, a single motor controller can supply a peak current of 20 amps. The 20 amps fuses mentioned earlier will suffice since these controllers will never draw that much current. For continuous usage, this current is 10 amps. In order for the laptop to receive the data acquired, a Breakout Board will be connected to the motor controller. This Breakout board, which is also made from quicksilver, acts as a parallel port converter so that a serial cable can be connect the laptop and motor controller. The motors on both channels will always spin in sync because we tell the motor controllers how fast we want the motors to spin. When the robot is making a turn, for instance, the motors will spin at the same speed, but in opposite directions.

3.3.4 Motors

The make of the two motors to be used with the motor controls mentioned above is the QuickSilver 34 – HC – 3. It was predetermined that these motors are sufficient for our application since they were used for TNA and they worked fine. These motors run at a maximum speed of 2000 RPM. For the best performance and efficiency, the speed should be 1000 RPM, however. The size wheels to be fitted on the motors are 14 inch pneumatic tires. A list of some of the specifications of these motors are as follows,

1. Permanent magnet type, 48Vdc maximum
2. With no load , max speed is 2000 RPM
3. Maximum power output is 580 Watts
4. Maximum current drawn from power source is 16 amps
5. Continuous stall torque is 13.8 newton-meters

3.3.5 Sensors

The vehicle has five main sensors to provide the necessary vision, obstacle detection and navigation data in order to effectively navigate the course. These sensor inputs include a LIDAR (SICK LMS221), cameras (Logitech Quickcam Pro 5000), and a GPS (Raven Invicta 115). Other sensors might be tacked on later such as a digital compass and/or an accelerometer.

3.3.5.1 LIDAR

To aid in the navigation process, we used a LIDAR device, model SICK LMS221, which can be seen in Figure 3 shown below. With this laser range-finder, our robot will be more aware of its environmental surroundings than a robot that would be using infrared or ultrasonic sensors. Data acquisition can occur since it communicates over a serial interface to the computer. This device can sweep 180 degrees (or 100 degrees) 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

1. 0.25 degree intervals, 100 degree range ==> 401 data values
2. 0.5 degree intervals, 100 degree range ==> 201 data values
3. 1 degree intervals, 100 degree range ==> 101 data values

4. 0.5 degree intervals, 180 degree range ==> 361 data values
5. 1 degree intervals, 180 degree range ==> 181 data values

For this competition, the setting that was chosen was setting number 5. A range of 180 degrees was necessary and a 1 degree interval was determined to be precise enough.

Figure 3: SICK LMS 221 LIDAR

3.3.5.3 Cameras

For obstacles that cannot be detected by the LIDAR, it is essential to integrate cameras into TINA. As a result, the robot will have four Logitech Quikcam Pro 5000 cameras. The field of vision of these cameras will cover 180 degrees in front and back of the robot. With this configuration, the robot will be able to detect and follow lines as well as stated in the IGVC rules of 2009. A picture of this camera can be seen in Figure 4. As mentioned earlier, a camera program has been created. With this program, TINA will be maximizing the usability of these relatively inexpensive cameras. This makes complete economic sense because we did not need invest as much money on cameras, such as stereo-vision cameras that cost thousands of dollars, like what other teams have done.

Figure 4: Logitech Quikcam Pro 5000 Camera

3.3.5.4 GPS

After knowing how accurate the robot has to be when finding the way-points in the navigation challenge, a differential GPS (DGPS) was chosen because a conventional GPS is only accurate to 3 meters without correction. Based on the demands this competition establishes, these features of a typical GPS do not measure up to such demands. The GPS chosen was the Raven Invicta 115 GPS receiver, which interfaces with the computer using a serial-to-USB converter. This DGPS has an accuracy of less than 1m. A photograph of it is shown in Figure 6.

Figure 5: Raven Invicta 115 GPS Receiver

3.3.6 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.

3.3.7 Performance

Table 1 below summarizes the predicted performance of TINA.

3.3.7.1 Maximum Speed

The following parameters where used in determining the theoretical maximum linear speed of the robot assuming no losses and level ground. The drive wheels have a 7 inch radius and the optimal angular speed of the motor is 1000 rpm. The product of the circumference of the wheel, which is found from the radius, and the optimal angular speed according to the company's specification sheet, yields 41.6 mph. However, since we are using a 10:1 speed reducer as mentioned earlier, the new predicted speed will be 4.16 mph, which is well within the 5 mph speed limit.

3.3.7.2 Battery Life/Run Time

The run time of TINA is solely based on the battery life of the laptop. This laptop acts as the "brain" of TINA so to speak and has a battery life of about 40 minutes. TINA has not been run down to see the real run time, but it should be around this figure.

3.3.7.3 Obstacle Detection

Based on the limitations imposed by the LIDAR, the expected maximum obstacle detection is about 8m. This has not been presently tested.

3.3.7.4 GPS Accuracy

When using differential correction signals, the RMS accuracy is less than 1m according to specifications. In addition, the GPS needs to have a line of sight connection with five satellites.

However, we have not been able to find how accurate the GPS actually is through testing as of now due to complications of the GPS itself.

3.3.7.5 Ramp Climbing

During the design phase, it was predicted that TINA should able to climb a ramp of about 27 % gradient or 15 degrees. To test this prediction, a ramp climbing test will be performed. Unfortunately, this characteristic of TINA has not been determined experimentally as of now. However, we do feel that since there will not be a ramp whose gradient is more than 15 % at the competition, TINA should be able to perform adequately in this respect.

3.3.7.6 Reaction Time

Although this has not been tested at this time, we estimated that this will be around 150 ms.

3.3.7.7 Power Consumption

Knowing that the two motors both need to draw at a total of 32 amps and the LIDAR draws 5 amps at 24 volts, the power consumption for the motors and the LIDAR are 768 Watts and 120 Watts, respectively. When the two are added, this yields 888 Watts of power consumption. Of course, this figure is an underestimate since there are more electrical components that TINA has than mentioned in this analysis. This was only to give us a decent approximation because power consumption was determined for the two biggest power consumers that TINA is equipped with. Again, these are the two motors and the LIDAR.

Performance Area	**Predicted Performance**
Maximum Speed	4.16 mph
Run Time/Battery Life	40 min
Longest Distance for Obstacle Detection	8 m
Differential GPS Accuracy (Waypoint Navigation)	< 1 m

Maximum Climbing Gradient	27 %
Reaction Times	150 ms
Power consumption	888 Watts

Table 1: Predicted performance results.

3.3.8 Vehicle Cost Breakdown

Included here in Table 2 shown below is a breakdown of the components used in construction of TINA. As mentioned earlier, the majority of the electrical components have been reused from our 2007 robot TNA.

Component	**Quantity**	**Actual Cost**	**Cost To Team**
SICK LMS 221 LIDAR	1	5,421.43	0.00
Quicksilver 34-HC-3	2	1,467.30	0.00
Raven Invicta 115 GPS	1	1,359.00	0.00
ZT Group Laptop	1	1099.99	1099.99
SilverNugget N3 Motor Controllers	2	777.60	0.00
Extruded aluminum and connectors		513.64	513.64
Logitech Quickcam Pro 5000 Webcams	4	346.40	0.00
Lead acid car battery	2	444.10	444.10
Polycarbonate 1/16” thick		122.80	122.80
Resistor Pack	2	107.20	0.00
10” castor wheels	2	32.99	32.99
14” drive wheels with split rims	2	69.96	69.96
LIDAR mounting bracket	1	76.50	0.00
Commando EZ-2500 wireless transmitter	1	69.99	0.00
Breakout modules for 34-HC-3	2	43.55	0.00

Electronic components (wires, fuses,etc)		23.12	23.12
4 port USB hub	1	11.99	0.00
Serial port to USB cable	1	8.99	0.00
Red 1.5” diameter emergency button	1	6.10	0.00
Boston Gear Speed Reducers with coupling and mount bracket	2	816.36	816.36
Miscellaneous Hardware (Bolts, lubricant, nuts, etc)		93.67	93.67
Voltage Clamp	2	227.80	0.00
Aluminum cylinder to make wheel hub	2	300.34	300.34
TOTAL		**13,440.82**	**3,216.63**

Conclusion

TINA 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. We would like to thank everyone who has dedicated their time, effort, and resources to setting up and running this event.