Stony Brook University
The Robot Design Team
TINA 2.0
(Terrain Independent Navigation Automaton)

Intelligent Ground Vehicle Competition 2010

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Faculty Advisor Statement

I certify that the design and creation of TINA 2.0 has been significant and is equivalent to what might be awarded credit in a senior design course.

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Professor Yu Zhou
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01/30/2010
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Date

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1. Introduction

The Robot Design Team of Stony Brook University is proud to present TINA 2.0 (Terrain Independent Navigation Automaton) for the 2010 IGVC competition. This autonomous robot is the end result of a collaborative effort of undergraduate students whose majors consist of applied mathematics and statistics, biology, biomedical engineering, computer science, electrical engineering, health science, mechanical engineering, and physics. TINA 2.0's design consists of both the best features from TINA, the 2009 robot, and some new features. The design improvements were made after a careful evaluation of TINA's strengths and weaknesses.

2. Innovations

The most significant mechanical innovation in TINA 2.0 is the two-part chassis. The chassis assembly consists of the driving module and the electrical and sensory module. The driving module is a rigid platform outfitted with a two motor drive system and support castors. The electrical and sensory module encloses the robot's power supply, computer, and sensor assemblies. Modular design allows significant changes to be made independently to either the driving system or the electrical and sensory system. The modules are fastened together by vibration dampening connectors to dissipate the vibrations of rough terrain and can be connected in six different orientations. Three of the orientations have the drive motors in the front of the robot, while the other three configurations have the drive motors in the back. A switch from one configuration to the next can be made relatively easily and makes TINA 2.0 a versatile test platform.

The power source has been updated for fast and easy accessibility. TINA 2.0 has been fitted with a sliding battery drawer, which allows for the batteries to be changed easily. This system also enables the batteries to be connected to the rest of the electrical system with ease and speed.

3. Design of TINA 2.0

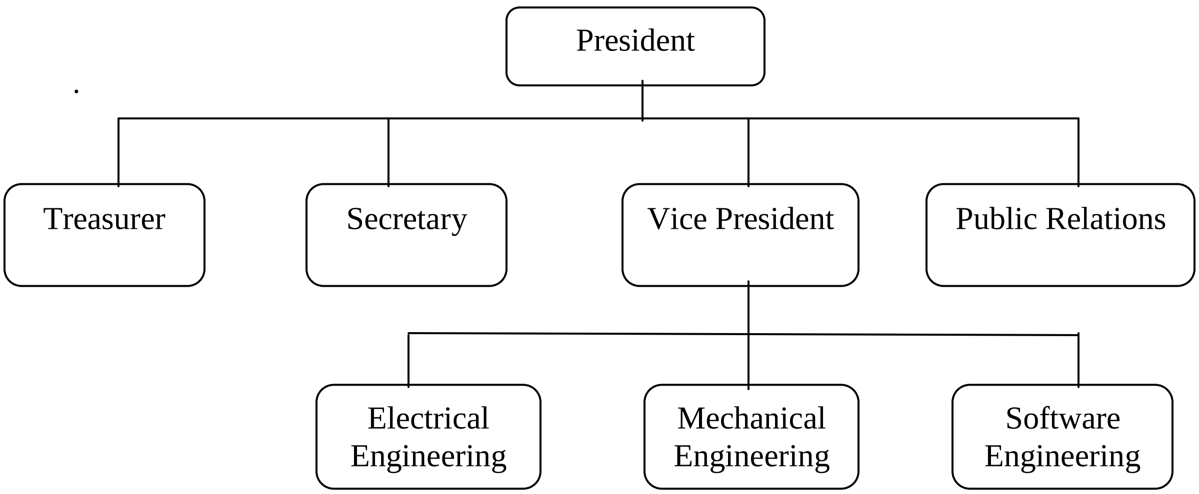
3.1 Team Structure

The president handles administrative duties and keeps track of overall progress, while the vice president manages individual projects and safety. The treasurer balances the accounts and purchases needed supplies, while the secretary takes care of paperwork and notifications to the team. The public relations team handles the team's image and recruitment activity

The team is divided into three sub-teams: Electrical Engineering, Mechanical Engineering and Software Engineering. An individual member usually belongs to one of these teams, depending on the particular member's skills and inclination. Each team is assigned to design a subsystem within the robot to perform specific functions. The sub-team leaders meet periodically to ensure that each design can be integrated into the robot and coupled to the other subsystems.

The overall organization is shown schematically in figure 1.

<u>Figure 1:</u>



3.2 Conceptual Design Phase

The basic design behind TINA 2.0 was the original TINA, the robot Stony Brook Robot Design Team fielded in 2009.

TINA 2.0 was originally designed to be an easily maneuverable system compared to TINA. Thus, the new robot was designed in two parts. The first part would be the drive system and the second part would be used to mount all of the sensors, laptop and electrical components. The initial idea was to have the two sections mounted together via bolts. This is shown in figure 2:

Figure 2 : CAD drawing of robot

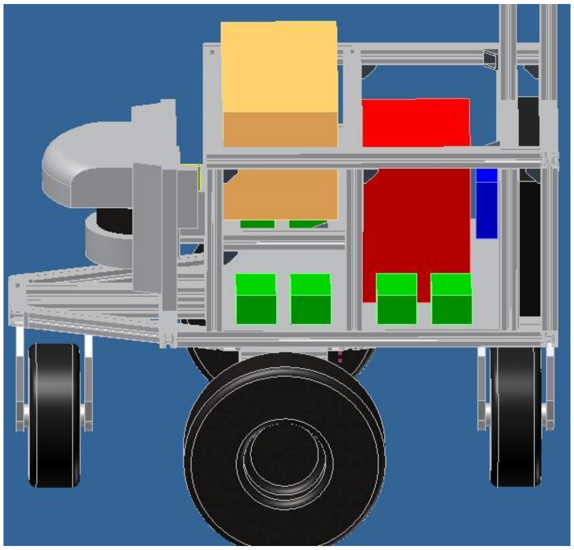


Figure 2 shows two drive wheels in the center with castors in the front and the back. This design was changed during testing due to vibrations that propagated through the structure. The solution to this problem was to put the two drive wheels on one end of TINA 2.0, with the two castors on the other end.

The structural of TINA 2.0 was made out of extruded aluminum. This decision was based on the ease in which the structure could be changed if needed. TINA was based on the same concept. The key difference is the way in which the aluminum was connected. The aluminum in TINA was connected with special connectors that were designed specifically for the aluminum by the manufacturer. These connectors added weight and cost to last year's robot. This year, the aluminum pieces were threaded and milled such that they could be bolted together whenever possible. There are some instances in which the geometry of the overall structure prevented bolts from being used. In these instances connecters were used to attach the aluminum. This can be seen in figure 2.

The batteries on last year's robot were two 50 lb lead acid batteries. In order to minimize weight, these batteries have been replaced by six lithium ion batteries. These batteries are able to provide the same amount of power as the lead acid batteries. The key difference is that all six lithium ion batteries only weigh about 15 lb.

3.3 Detailed Design Phase

In this stage of the design process, most of the basic elements of the robot had already been determined. The key features are noted in this section along with the solutions to problem that we came across during the process.

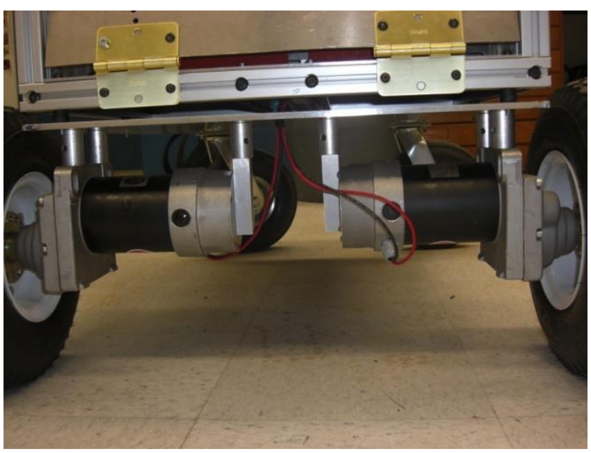
3.3.1 Mechanical Design

The mechanical team was in charge of the physical aspects of the structure, including how the robot will react to the environment. This also included the mounting of all electrical and computer hardware components that were needed for the overall system.

3.3.1.1 Drive Train

The robot is fitted with a direct differential drive system. The drive train consisted of two new DC geared motors that had gearboxes built in. Motion is provided by a single pair of powered wheels which are aligned along an axis perpendicular to the direction of forward drive. Each wheel is directly attached to a motor whose velocity and acceleration can be controlled independently of the other. Individual motor control allows the robot to execute a variety of maneuvers including turning, forward and reverse motion, and curved motion. Turning would be performed by having one wheel turn forward, while the other wheel would turn backwards. The drive motors are shown below in figure 3:

Figure 3: Drive motor configuration



The two motors used were 24 V DC motors from NPC Robotics. These motors were donated to the team; they are not made anymore, so a cost of purchasing these motors is unknown. These motors run at a maximum speed of 240 rpm. However, for the best performance and efficiency, the speed should be 100 rpm. The wheels fitted on the motors are 14 inch pneumatic tires.

Besides the drive wheels, the system is supported by two support castors to ensure four points of contact on level ground. Such a configuration allows a constant four points of contact even on the ramp under the condition that the robot is driven parallel to the boundary lines. The four tires are located on the corners of the robot such that if their points of contacts were connected, its foot print would make a trapezoid. The robot was designed to fit within this trapezoid in order to limit the effects of vibration that weight can have on the system. The wheels and castors are pneumatic tires which can deform by about 0.5” and conform to the terrain. The flexibility of pneumatic tires eliminates the need for a suspension system on terrains such as concrete, asphalt, and grassy plains with smooth inclines.

3.3.1.2 Frame

Modular design is used to maximize versatility of the robot as well as to isolate the drive system from the electrical and sensory system. The drive train system is mounted to sheet stock aluminum, which is known as the bottom section. The electrical and sensory systems are mounted to sheet stock aluminum as well as to extruded aluminum, which is known as the top section.

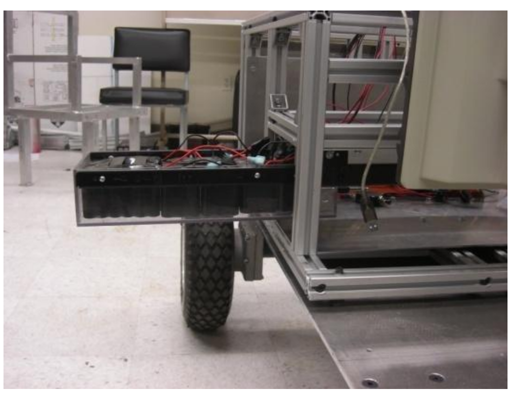
The extruded aluminum makes up the frame of the robot. Aluminum extrusion would be used for the frame since it is durable, lightweight and inexpensive. Assembly is relatively easy because of the fixtures made specifically for this type of building material. For example, if something mechanically wrong occurs during testing, the frame can be easily taken apart and proper modifications can be made. These pieces of aluminum were milled and threaded such that they can be connected to one another by bolts. Notches were milled in the aluminum such that once they were bolted together; there would be zero degrees of freedom. The threading allowed the bolts to attach pieces of aluminum together. There were some instances in which the bolt could not be used to hold the aluminum together due to the constraints of the system. In these cases, connecters were used to bolt the aluminum together.

One issue that we found was the vibrations induced from the overall system. This was corrected by connecting the top and bottom sections with rubber dampeners. These pieces of hardware dissipated some of the energy from the environment that would go into displacing the sensors and other devices in the system. The two sections can be connected in six different configurations. Three of these configurations have the drive wheels in the front of the robot, and the other three configurations have the drive wheels in the back of the robot. This was done for versatility. If at any point, the dynamic motion of the robot is undesirable, it can be changed relatively easily. Changing the placement of attachment for the two sections changes the center of gravity, which will affect the overall motion.

3.3.1.3 Battery Box

Six lithium ion batteries were used in TINA 2.0. In order to charge these batteries, they must be taken out of the robot. To do this, a battery box was designed to make changing batteries easy. The box itself is made of polycarbonate plastic that is attached via a solvent which renders the entire box solid. The box is mounted to a set of rails. These rails keep the box in place in the robot until a significant force is placed on the box that is parallel to the motion of the rails. This will allow for the box to move relative to the robot, which allows for the batteries to be changed. The batteries are connected in sets of two and are connected to wires that run along the box. The wires connect to connectors on the box that connect to corresponding connectors in the robot when the box slides into the robot. The battery box is shown in figure 4:

Figure 4: Battery Box with batteries



3.3.1.4 Sensors

All of the sensors that are used on this robot had to be rigidly mounted. The Lidar is attached to a piece of extruded aluminum that is able to move up and down since it is only connected to the other pieces of aluminum with connectors. This was done so that the plane on which the Lidar can see can be adjusted. A GPS was mounted on top of a tower of extruded aluminum. This allows for the GPS to be as high as possible so that it won't interfere with the other electrical components. The cameras that are used this year were not designed to be mounted in the manner that we needed, thus a camera mount was designed out of aluminum. Two pieces of aluminum are bolted together such that the camera is held tightly. This is shown in figure 5.

Figure 5: Camera Mount

3.3.1.5Weatherproofing

Weather proofing took considerable consideration in the design of this robot. Since the robot would be expected to perform even during rain, it must be ensured that all of the electrical components are safe from water. Sheets of polycarbonate plastic will be applied to the extruded aluminum structure to prevent anything from entering into the system. This posed a problem to the ease of access of the components of the robot. Directly attaching the polycarbonate to the robot would make it difficult to get to the electrical components easily if anything needed to be adjusted. To remedy this, the plastic will be mounted on plastic hinges and kept in place via a locking mechanism. The hinges will allow for the weather proofing to be moved easily such that the electrical components can be accessed when needed and yet the system will be protected from the weather.

The motors were attached such that they would be exposed to the environment. To protect the motors from being hit by debris, polycarbonate plastic will be attached to the bottom section in order to encase the motors, in such a way that they will be protected.

3.3.2 Electrical Design

The electrical team had several key responsibilities. This included making sure that each sensor and motor were wired properly. The wiring had to be done in such a way that the wires were neatly ordered. New batteries had to be found that would be able to handle the application of the competition. The biggest task of this team was to ensure the electrical safety of the robot.

The power source of TINA is six 12 volt lithium ion batteries. Two batteries connected in series for a total voltage of 24 V will be supplied to the motors and motor controllers, which draw about 30 amps overall. Another two batteries will supply power to the camera and LIDAR. There will be an extra two batteries on the robot which will be used as a fallback power source. All of our electrical components run on 24 volts, so this eliminates the need for a dc/dc converter to 12 volts. The cameras are powered by the laptop. The motor used this year was a 24 V DC motor from NPC Robotics. For safety purposes, the majority of the electrical components, including each motor, will each have its own designated 20 amp fuse. Also, a control panel switch board was implemented so that motor, GPS, and LIDAR can be easily turn on or off using a switch. For wire neatness and connectors and terminal blocks were used.

3.3.2.1 Motor Controllers

The motor controllers were model AX1500, sourced from RoboTeq. It takes a custom made program and commands each motor individually using a serial interface. It can power two motors individually up to 30 amps. They will ensure that the motors on both channels will always spin in sync. When the robot is making a turn, for instance, the motors will spin at the same speed, but in opposite directions. The primary means of controlling the robot's path involve VMI, which allows the robot to change velocities, start, or stop at any point.

3.3.3 Software Design

The software engineering team was in charge of programming the robot to be able to run autonomously. This includes determining which sensors would be needed for the robot and programming each individual sensor and the system as a whole.

3.3.3.1 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 (Microsoft LifeCam Cinema camera), and a GPS (Raven Invicta 115). Other sensors might be added later, such as a digital compass and/or an accelerometer.

3.3.3.1.1 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. 0.50 degree intervals, 100 degree range ==> 201 data values
3. 1.00 degree intervals, 100 degree range ==> 101 data values
4. 0.50 degree intervals, 180 degree range ==> 361 data values
5. 1.00 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 1.00 degree interval was determined to be precise enough.

Figure 6: SICK LMS 221 LIDAR

3.3.3.1.2 Cameras

For obstacles that cannot be detected by the LIDAR, it is essential to integrate a camera into TINA 2.0. As a result, the robot will have one Microsoft LifeCam Cinema camera. 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 program was created that uses feedback from the camera to help in the process of mapping and localization. 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.

Figure 7: Microsoft LifeCam Cinema Camera

3.3.3.1.3 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 within three 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 within one meter. A photograph of it is shown in Figure 8.

Figure 8: Raven Invicta 115 GPS Receiver

3.3.3.2 Overall System Software Design

The software is constructed using C# in Microsoft Visual Studio 2008, 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.

3.3.4 Performance

Table 1 below summarizes the predicted performance of TINA 2.0.

3.3.4.1Maximum 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 100 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 4.5 mph, which is well within the 5 mph speed limit.

3.3.4.2 Battery Life/Run Time

The run time of TINA 2.0 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 2.0 has not been run down to see the real run time, but it should be around this figure.

3.3.4.3 Obstacle Detection

Based on the limitations imposed by the LIDAR and our environment, the expected maximum obstacle detection is about eight meters. This has not been presently tested.

3.3.4.4 GPS Accuracy

When using differential correction signals, the RMS accuracy is within one meter 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 with the GPS itself.

3.3.4.5 Ramp Climbing

During the design phase, it was predicted that TINA 2.0 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 2.0 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 2.0 should be able to perform adequately in this respect.

3.3.8.6 Reaction Time

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

3.3.8.7 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 2.0 is equipped with. Again, these are the two motors and the LIDAR.

Performance Area	**Predicted Performance**
Maximum Speed	4.5 mph
Run Time/Battery Life	3 hours
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.

3.3.9 Vehicle Cost Breakdown

Included here in Table 2 shown below is a breakdown of the components used in construction of TINA 2.0. Some of the components were reused from TINA in order to lower cost.

Component	**Quantity**	**Actual Cost**	**Cost To Team**
SICK LMS 221 LIDAR	1	5,421.43	0.00
24 V DC motors	2	unknown	0.00
Raven Invicta 115 GPS	1	1,359.00	0.00
ZT Group Laptop	1	1099.99	0.00
AX1500 Motor Controller	1	300.00	300.00
Extruded aluminum		300.00	300.00
Microsoft LifeCam Cinema camera	2	79.98	79.98
Lithium Ion batteries	6	660.00	660.00
Smart charger	6	185.93	185.93
Polycarbonate 1/16” thick		122.80	0.00
10” castor wheels	2	32.99	0.00
14” drive wheels with split rims	2	69.96	0.00
LIDAR mounting bracket	1	76.50	0.00
Commando EZ-2500 wireless	1	69.99	0.00

transmitter			
Electronic components (wires, fuses,etc)		20.00	20.00
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
Sheet Aluminum	2	300.00	300.00
Miscellaneous Hardware (Bolts, lubricant, nuts, etc)		100.00	100
Voltage Clamp	2	227.80	0.00
Rubber Dampeners	2	40.00	40.00
TOTAL		**$10,493.45**	**$1,985.91**

4. Conclusion

TINA 2.0 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.

5. References

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2. http://www.itbookworm.com/xmaslist2009/images/MSLifeCam.jpg

3. http://www.brandnermapping.com/ASST0100016.jpg