Roy

5/12/2011

CSULB Autonomous Lawnmower Entry 2011 ION Robotic Lawnmower Competition

Abstract: Last year California State University, Long Beach participants had a dream that students would take on ROY to improve it and make it better. This year would be CSULB's second time competing in the ION Robotics Lawnmower Competition. We have a new team and have improved ROY. ROY is a work that shows the dedication and passion of students to learn something that is totally new to them. The Purpose of this report is to outline each component of ROY, our lawnmower in detail.

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INTRODUCTION

California State University, Long Beach (CSULB) will be competing for the second time in the 2011 ION Robotic Lawnmower Competition. We adapted the project from the previous members who competed in the 2010 ION Robotic Lawnmower Competition. It is our pleasure to introduce ROY to the ION Robotic Lawnmower Competition.

ROY received its name based on an amazing dog that was present at the first team's meeting from the previous team. The real Roy was full of life, curious, encouraging and lived as if he were bigger than he really was. Although the real Roy is no longer with us, his qualities carried over into the build of this mower and therefore we decided to honor him by giving our lawnmower his name.

ROY was created from the ground up with attention to detail in every aspect. This is the first year any of us will be competing in a robotics completion. Although the project was passed down to us, we have spent a lot of time making the physical product stable and learning the technology. Like the pass group, almost everything that is used to build and make ROY run is new to us. Our primary goal was to make what we have stable because we notice that a lot of the equipment was damage due to last year's transportation method. The lawnmower was disassemble and flown to Ohio last year. As we discover a lot went wrong after the competition.

As of the date that this report is being written, we have accomplished most of our goals. There are two issues that we are taking care of from this point on. One is fixing a problem we have with our LIDAR and cleaning up the grass cutting algorithm. A change that we are making to the lawnmower toward the end is to change the remote control. We are currently using a simple remote control, but we got a donation from a hobby store. The store gave us an airplane hobby remote control.

The experience of taking part in this competition has been one of the most challenging and rewarding aspects of our collegiate years and it is our hope that the students at CSULB continue to build upon ROY for future competitions.

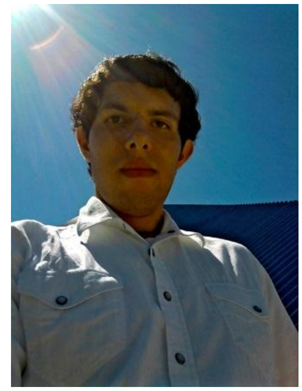
We would like to thank our faculty at CSULB for their support, NavCom Technology, Inc. for their generous sponsorship, and the Institute of Navigation for giving us this autonomous challenge.

Team ROY, 2011

TEAM OVERVIEW

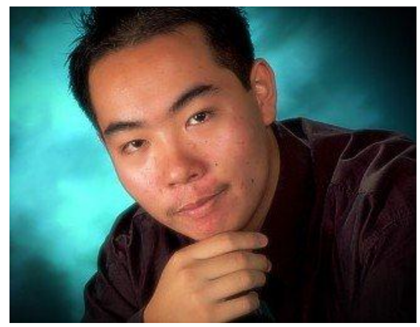
The 2010- 2011 CSULB team is composed of the following three students:

Jose Trujillo



I am currently a fourth year college student at Cal State Long Beach, and working on getting my bachelors in Computer Engineering. I have experience in Java, C++, C#, and am currently learning app development for the Windows Phone 7 and 3D modeling using Maya and ZBrush. I am currently an officer of the Embedded Applications Technology organization as a representative for our college of engineering student organization board. I have also done some volunteer work in Costa Rica doing sea turtle conservation in a small city named Gandoca.

David Tran

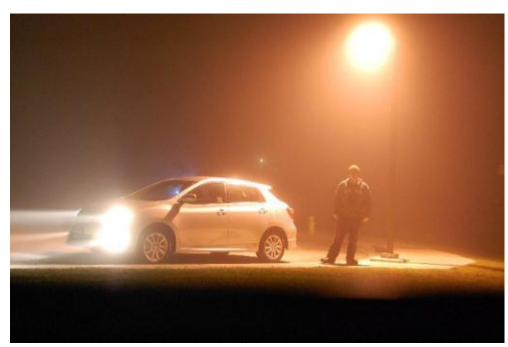


I am a third year computer engineering student at Cal State Long Beach. I put a lot of effort into my work and also to help others. Being expose to the world of electronics at an early age, I am very fascinated by hardware and how they are built. When faced with a hardware obstacle, I fabricate my own custom parts from scratch when possible. Computer engineering is not my only interest. I like to repair automobiles, houses, or anything that can be fix. The ION Autonomous Lawn Mower competition will be my first engineering competition, but overall I hope for a fun experience and to meet new people.

Bryant To

Hello everyone. I am a 3rd year in CSULB going for a BS in Computer Engineering. I've spent a lot of time learning about electronics and how they work by taking things apart or learning through the internet. When not studying, I like to play games, preferably RPGs, Shoot-Em-Ups, and puzzles, but I dislike First-Person Shooters though. I also like to read mangas, watch anime, draw, and do a bit of martial arts.

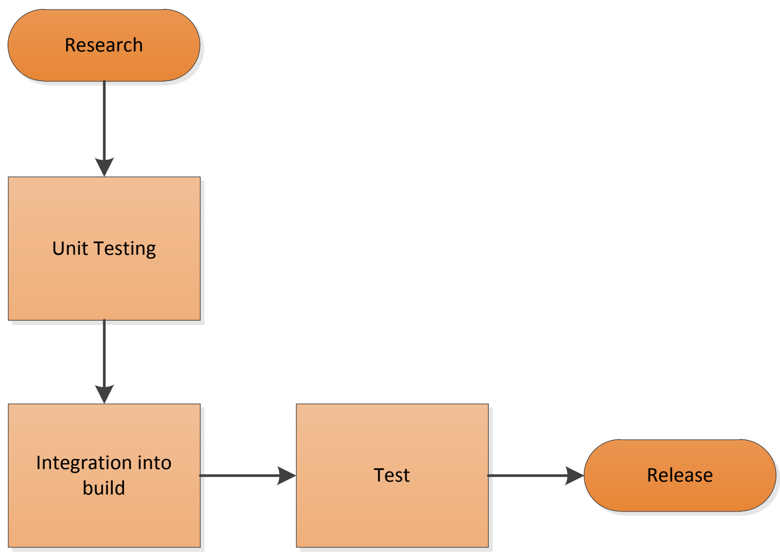
James Coolidge



For those not familiar with me, I am an engineer by nature with a propensity to tinker with just about anything. Sometimes, I try and repurposing some broken hardware for other means. Some of my projects I have done include turning a camera into a taser, making an electromagnet out of speaker coils, and making a high impulse magnet out of a taser and an electro magnet. Aside from my summer projects, I spend most of my time during the school year buried in schoolwork, working on projects, or enjoying the company of fellow classmates in the EAT room.

BUILD PROCESS

In developing a build plan we considered the dynamics involved with creating a complex autonomous lawnmower. None of our team members have ever taken part in a project of this magnitude so we wanted to pace ourselves in a realistic manner. As envision by last year group, the moreover was adapted by this year's group. We followed along their footsteps on our build process. We began with a solid vision of what needed to be done and our main objective was to get the tasks done in a timely manner as well as enjoy the ride. With this in mind, set ourselves to work on ROY. The diagram below shows our building process.



Since our lawnmower was built from the ground up it was necessary for all of the new people involved to learn everything they could about the equipment that is used on ROY. Phase one of the building process was research, the main research was done by David. David reported to the other team members to help them understand and operate the equipment. Phase two of the building process was unit testing; this was mainly done by Bryant. Some of our equipment was damage during the flighty back last year. Bryant was in charge of making sure all the equipment was in operational condition. Phase three of the building process was integration into build, this was James responsibility. There were a few changes made to make the mower wiring and equipment stable so that no wire will come off when we are in competition as it did last year. Phase four of the building process was testing; this was mainly done my Jose. Jose was making sure that all the bugs that existed in the coding got clean and that we have a stable software system. Finally, we worked together in the last phase. For the most part we tried to remain loyal to this process although at times the duties would swap due to necessity.

SCHEDULE

Once we determined a build plan we prioritized each component and created a schedule. We tried our best to adhere to the timing but we did fall behind at some points and we didn't complete other tasks (such as find a better functionality for the LIDAR, because we believe it is a powerful tool we can use in a more efficient way).

	December	January	February	March	April	May
Initial Planning						
Assemble Team						
Research 2011 Requirements						
Research						
Mower Schematic						
GPS Units						
Remote Control						
Encoders						
RTK Radio Units						
LIDAR						
Software						
Test GPS						
Test RTK						
Test Encoders						
Test LIDAR						
Hardware						
Organize wires						
Fix LIDAR						
Build new encoders						
Fix RTK unit						
Integration						
Add encoders						
Add RTK for GPS						

PROJECT GOALS

As mentioned above, we began our journey with lofty goals. We wanted our mower to be innovative, eco-friendly, affordable and extremely precise. However we knew that we had to start humbly and work our way up from there. Therefore, our goals in order of priority were as follows:

1) Build a safe, functional autonomous lawnmower
2) Improve upon performance and robustness
3) Replace purchased parts with parts that we built ourselves
4) Make the robot eco-friendly

For each step we weighed out our options and considered the possibilities. For example, once we had a functional mower we wanted to develop our own components to drive down the overall cost. NavCom Technology, Inc. generously loaned us an extremely accurate GPS unit, two RTK units and a powerful LIDAR. These components are excellent but they make our lawnmower unaffordable to the average consumer. Therefore, we wanted to eventually improve upon the obstacle detection and replace the LIDAR with inexpensive detection units while offsetting the loss in capability by improving the lawnmower's "intelligence". Moreover, we considered adding solar-power to our lawnmower but that will also have to wait for another year as time didn't permit us to look into this option.

DESIGN CONCEPT

Several aspects were considered as we considered the lawnmower's design. These focal points are as follows:

1) Safety
2) Accurately traversing a field autonomously
3) Durability
4) Produce an aesthetically pleasing cut
5) Cost

Safety

Our primary concern throughout this process has been overall safety. As with all things autonomous the overall goal is to complete a task with minimal human counterparts. Of course this implies that the robot must not only complete the task but it must do so in a safety-first manner. During every step in the build we constantly asked ourselves if the design and implementation satisfied our absolute need for safety. In purchasing/creating each part we made sure that we only used components from reliable resources. Moreover, our safety features include:

a) A remote control that overrides the automation
b) An easily-accessible e-stop push-button mounted to the top of the mower which renders the mower immobile
c) A watchdog timer to disable the mower if the software enters unexpected states
d) Low maximum speed

A comprehensive discussion of each feature is discussed within this report.

Accurately traverse a field autonomously

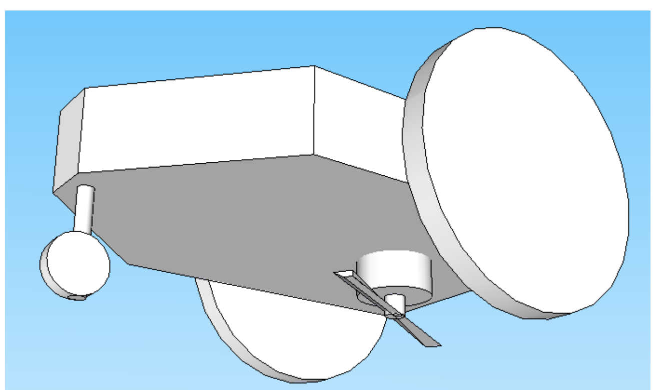
The accuracy of our mower was of utmost importance in our design concept. When a human mows a lawn he/she is constantly aware of the surroundings and we knew that our lawnmower would need to imitate the same awareness. In order to obtain this awareness we would need to know details such as current position, speed, obstacle detection, and boundary restrictions. Moreover, in adding these components to the mower we also needed to mount them in strategic locations while paying attention to proper weight distribution.

Durability

Considering the nature of a mower, durability was decided to be a major factor in the design process. We wanted to construct a mower that was lightweight, modifiable if necessary, and highly durable as the operation conditions could range from moderate to rough. Our research directed us to use T-Slot framing aluminum as for our chassis material. The details of this framing are described in the report. With T-slot framing we found a material that satisfied all of our requirements. Perhaps the most pleasing aspect was its ability to be modified as necessary. As we added parts to the mower and changed the design concepts due to performance issues, the t-slot framing was easily reconfigurable and extremely durable.

Produce an aesthetically pleasing cut

Since the overall goal of the competition is to mow a field in an aesthetically pleasing manner we took into account the importance of the actual "mower" during the design process. We decided that we would purchase a pre-made lawnmower and use its blade and motor for our design. Moreover, we wanted the blade to extend to the edges of the chassis without protruding past the edges. Our reasoning was that the mower should maximize the area cut as it traveled while remaining safety-conscious. A sketch of our initial concept is shown below:



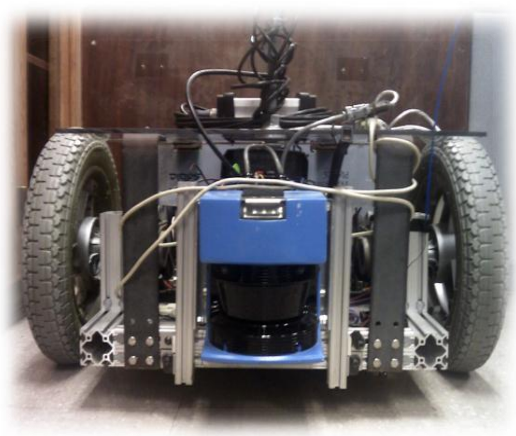
As you can see, the blade was intended to cover the length of the chassis. Moreover, we wanted to have the ability to do zero-degree turns so we opted to use two driving wheels with differential drive and one trailing wheel for balance. The zero degree turn would allow us to have better control around corners and edges than using a sweeping turn.

When we began to build the mower we kept our design concept in mind. However, one thing that we did not consider was "hard to reach" areas of grass that were impossible to reach due to the distance between the edge of the wheels and the length of the blade. This "gap" hindered our ability to cut the grass near the border and the grass surrounding obstacles. We are currently looking in a way of taking care of this issue.

Cost

Finally, our last concern with the design was the overall cost. The two driving factors were our team's budget as well as a consumer's ability to afford such a practical unit. We would like to see this project extend beyond competition and become a common device found in most households. As we researched our components we attempted to obtain parts that were low in cost but we quickly realized that in order to truly drive down costs we would need to manufacture as much as possible.

The final design of our lawnmower (95% complete) is shown below.



Front View

Side View

HARDWARE OVERVIEW

The hardware section of this report is divided into the following sections:

1) Mechanical
2) Electrical

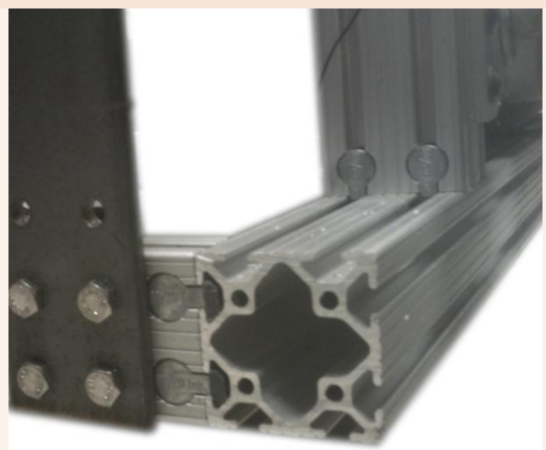
The mechanical section includes all of the hardware components that are basic necessities for a functional lawnmower. The electrical section includes all of the components that allow this lawnmower to be powered and autonomous.

Mechanical

Chassis

As mentioned earlier, durability, modifiability, and weight were the deciding factors in the material for the chassis. We decided to use aluminum t-slot framing for our construction. T-slot framing is based upon 6105-T5 aluminum which is a high strength alloy comparable to steel. The upsides are that it is lightweight, rust-resistant, and welding isn't necessary. The reason that welding isn't necessary is due to the actual slots that exist within frame itself. As you can see in the figure to the right, the frame of this aluminum has a profile in which a fastener can be inserted and tightened in place.

Specifications	
Material Used	T-Slot Aluminum Alloy
Cost	$300.00
Purchased from	Prime Resource



With this slotting capability, the chassis could be configured and fastened easily. When the fastener is tightened a 2 degree drop lock feature causes the t-slot flange to be flexed up by 2 degrees essentially "locking" the fastener into place. With this configuration, the connection points are extremely secure and resistant to the loosening effects of vibration and movement. Moreover, by releasing the fastener, the framing can be easily reconfigured and this proved to be beneficial as the overall layout was modified a few times due to wheel positioning and balancing.

External Covering

Specifications	
Material Used	Lexan
Cost	$210.00
Purchased from	Prime Resource

The electronics of the mower needed to be protected from the harsh environmental conditions commonly experienced in a mowing field. Therefore, we decided to create a shell around the t-slot framing using a material called Lexan. Lexan is an incredibly durable "plastic-like" material that has some flexibility to it. It is the same material that is used for football helmets and bullet-resistant windows. After testing this material we were very pleased with its toughness. We chose to tint it in order to reduce the direct sunlight that would enter the mower. Moreover, in order to reduce the heat within the covering we cut an opening and attached an air filter to the opening. By doing this the internals could "breathe" while the air filter stopped debris from getting in.

Mower Motor and Blade

We decided to use the parts from a store-purchased lawnmower for the task of mowing the field. The purchased lawnmower was the Earthwise 60020 electric lawnmower. This lawnmower is equipped with a 20 inch blade and the blades motor is powered by a 24 volt power source. Initially, we mounted the motor and the blade directly onto the base of the chassis but we realized that there was a ½ inch distance between the blade and the edge of the chassis on all sides. Since we wanted to cut as much grass as possible under the mower, we replaced the 20 inch blade with a 21 inch blade which slightly increased overall performance.

Specifications	
Product	Earthwise 60020
Cost	$269.98
Purchased from	Amazon.com
Input Voltage	24 Volts
Blade Size	20 inches
Application	Cuts the grass

Wheel Motors

Specifications	
Product	Pride Jazzy 1470 motors
Cost	$200.00
Purchased from	EBay
Input Voltage	24 Volts
Application	Spins the wheels

While researching the parts we predicted that the mower's weight would be between 150-200 pounds. Considering the weight requirements and the maneuverability that we deemed necessary, we decided to incorporate wheelchair motors into our design. The Pride Jazzy 1470 Wheelchair motors were our motors of choice as they provided us with excellent control with a maximum weight capacity of 500 pounds. The wheels that are attached to these motors are 16 inches in diameter which are perfect for open field terrain. Moreover, the motors are adjustable in speed which enables us to remain within the speed limit for the competition.

Electrical

Computation Devices

In order to compute and process the data, we used a microprocessor and a laptop computer. The microprocessor is a LPC2148 microcontroller which uses an ARM7 as its processor. The laptop is a Compaq Presario V500.

dGPS

Specifications	
Product	NavCom SF-3050
Cost	N/A
Sponsor	NavCom Technology, Inc.
Input Voltage	12 Volts
Accuracy (RTK)	1cm + .5ppm (horizontal) 2cm + 1ppm (vertical)
Accuracy (Starfire)	< 10 cm (horizontal) < 15cm (vertical)
Application	Obstacle detection (secondary)

NavCom Technology, Inc. generously provided our team with their SF-3050 unit which provides incredible accuracy at any point in time anywhere in the world. As a stand-alone device, the device uses StarFire technology which is accurate within 10cm horizontally and 15cm vertically. Starfire is a Differential Global Positioning System (dGPS) which is an enhancement to Global Positioning System (GPS). Although 10cm accuracy is excellent for most applications, the unit can be combined with a second SF-3050 to significantly increase the accuracy by applying StarFire RTK (Real Time Kinematic) technology. Combining the two devices is accomplished by placing one unit on the lawnmower (rover) and placing the second unit in a nearby location (base). The base unit performs its own dGPS calculations and sends these corrections to the rover unit resulting in 1cm horizontal accuracy and 2cm vertical accuracy.

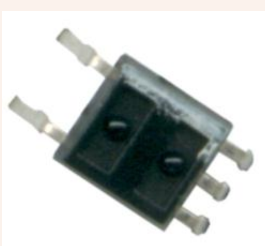
LIDAR

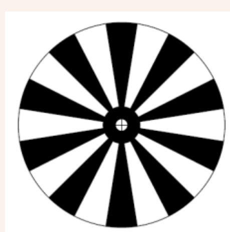
Our primary source of obstacle detection is the Sick LIDAR (Light Detection and Ranging). It uses an eye-safe laser that is sent in pulses from a rotating mirror. If the laser hits a surface the signal is reflected back to the LIDAR and the time delay determines the distance of the object. The rotation of the mirror allows up to 180 degrees of obstacle detection with a range of 80 meters. Although this device is incredibly reliable and accurate, this particular model can be dazzled by direct sunlight producing erroneous readings. We placed a visor on top of the LIDAR in order to minimize direct sunlight from reaching the mirror but we decided to also implement a back-up obstacle detection device (sonar rangefinder).

Specifications	
Product	Sick LMS 210 LIDAR
Sponsor	NavCom Technology, Inc.
Input Voltage	24 Volts
Light Source	Infrared
Laser Class	1 (EN/IEC 60825-1), Eye-safe
Scanning arc	180 degrees
Range	81 meters
Application	Obstacle detection (primary)

Encoders

Specifications	
Product	CSULB Smart Spin
Cost for Parts	$5.00 each (x2)
Input Voltage	3.3 Volts
Resolution	Adjustable
Application	Determine the turning rate of the wheels



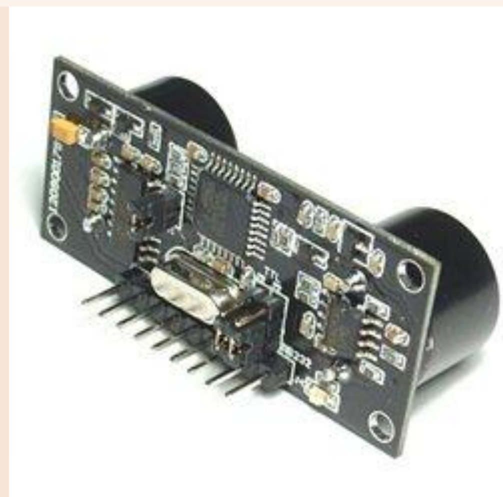


In order to determine speed and turn angles we decided to implement an encoder for each wheel. Although we could have purchased these, our team decided to build them ourselves. Our encoders consist of two parts: First, we used a C# program to create a circular image with black and white transition lines evenly spaced. By using a program to draw the diagram the resolution could be increased or decreased as we saw fit with excellent line-quality. Second, we incorporated a Hamamatsu infrared photo reflector (Part #475 1239-1-ND) to detect the black and white line transitions on the image. A rotating bolt protrudes from the rear-end of the wheel motors which spins as the wheels spin. Since the rotation of the bolt is in direct proportion to the rotation of the wheels, we attached the resolution image to the bolt. By doing this, the image would spin as the wheels turned. We then mounted the photo reflectors to the motors facing the image so that they would “see” the black and white transitions as the image spun. As the wheels turned, the photo reflector could determine the rotation rate by the black/white transition rate. Implementing the encoders was necessary to accurately determine 90 degree and 180 degree turns, that way, if one wheel would spin faster than the other, we would know that we were experiencing slippage or uneven terrain.

Sonar Rangefinder

Since the LIDAR can produce erroneous readings due to direct sunlight, we decided to implement a second obstacle detection unit. The unit of choice is the DFRobot URM V3.2 Ultrasonic Range Finder. This is a very inexpensive device that works quite well to detect obstacles. The LV series for this range finder comes in various detection widths and distances. A wider beam angle results in a smaller range and a thinner beam angle results in a longer range. We selected the EZ1 model which provides a wide beam angle. The reason that we selected this model is based on our necessity to detect immediate obstacles while this rangefinder is overriding the LIDAR due to faulty LIDAR readings. With a one meter detection range we are able to keep the lawnmower responsive and safe.

Specifications	
Product	DFRobot URM V3.2
Cost	$26.00
Purchased from	RobotShop.com
Input Voltage	+5 Volts
Range	4cm-5cm
Application	Obstacle detection (secondary)



Motor Controllers

Specifications	
Product	IFI Victor 883
Cost	$140.00 each (x2)
Purchased from	The Robot MarketPlace
Input Voltage	24 Volts
Cont. Current	60 Amps
Surge Current (2 sec)	100 Amps (1 second) 200 Amps (2 seconds)
Minimum Throttle	10%
Application	Powers the wheel motor

We decided to use the IFI Victor 883 motor controllers to control the wheel motors. These motor controllers have adjustable output control ranging from 10% to 100%. This allows us to easily adjust the speed of the wheels and maintain constant velocity control. Moreover, the motor controllers have reverse/forward drive options which is necessary for full autonomous control and overall differential drive. Its electrical strengths are that it can handle high continuous current draws as well as extreme current surges. Further, the motor comes with an attached cooling fan to ensure that the controller is constantly operating under acceptable temperatures. Another noteworthy quality is that it has an excellent braking system.

Remote Control

Specifications	
Product	Aero Sport5 Remote Control
Cost	$50.00
Purchased From	Hobby People
Max Distance	Approx 1mile
Operating Frequency	2.4GHz
Application	Drive the mower manually

Although the lawnmower is fully autonomous, we have a remote control feature which allows a user to interface directly with the mower. This remote control has priority in the software so it will override the lawnmower if it is operating in autonomous mode. We selected a remote control that has both sufficient range and excellent control. The Aero Sport5 remote control that we selected has a range of 1 mile and it has up to 5 channels. One channel is for going forward and backward and the second channel is to steer left and right. We have a dedicated channel for remote emergency stop. Implementing this remote control allows us to navigate the lawnmower when it is outside of the designated field. It also makes our lawnmower extremely safe as the user can take full control of the lawnmower at any time, even if the lawnmower is in the middle of autonomous operation.

Push-Button Emergency Stop

Specifications	
Product	IDEC HW1B-Y2F01-R
Cost	$28.00
Purchased From	Allied Electronics
Button Size	40mm
Button Color	Red
Application	turns off all motors

We have included an emergency stop push-button onto our lawnmower for safety purposes. The push button is large enough to locate when the lawnmower is working at full speed in autonomous mode. Further, it is easily accessible as it is located on top of the lawnmower. When the button is pressed it cuts off the power source from the motors causing the lawnmower to come to an immediate halt.

The implementation of this emergency stop makes our lawnmower extremely safe.

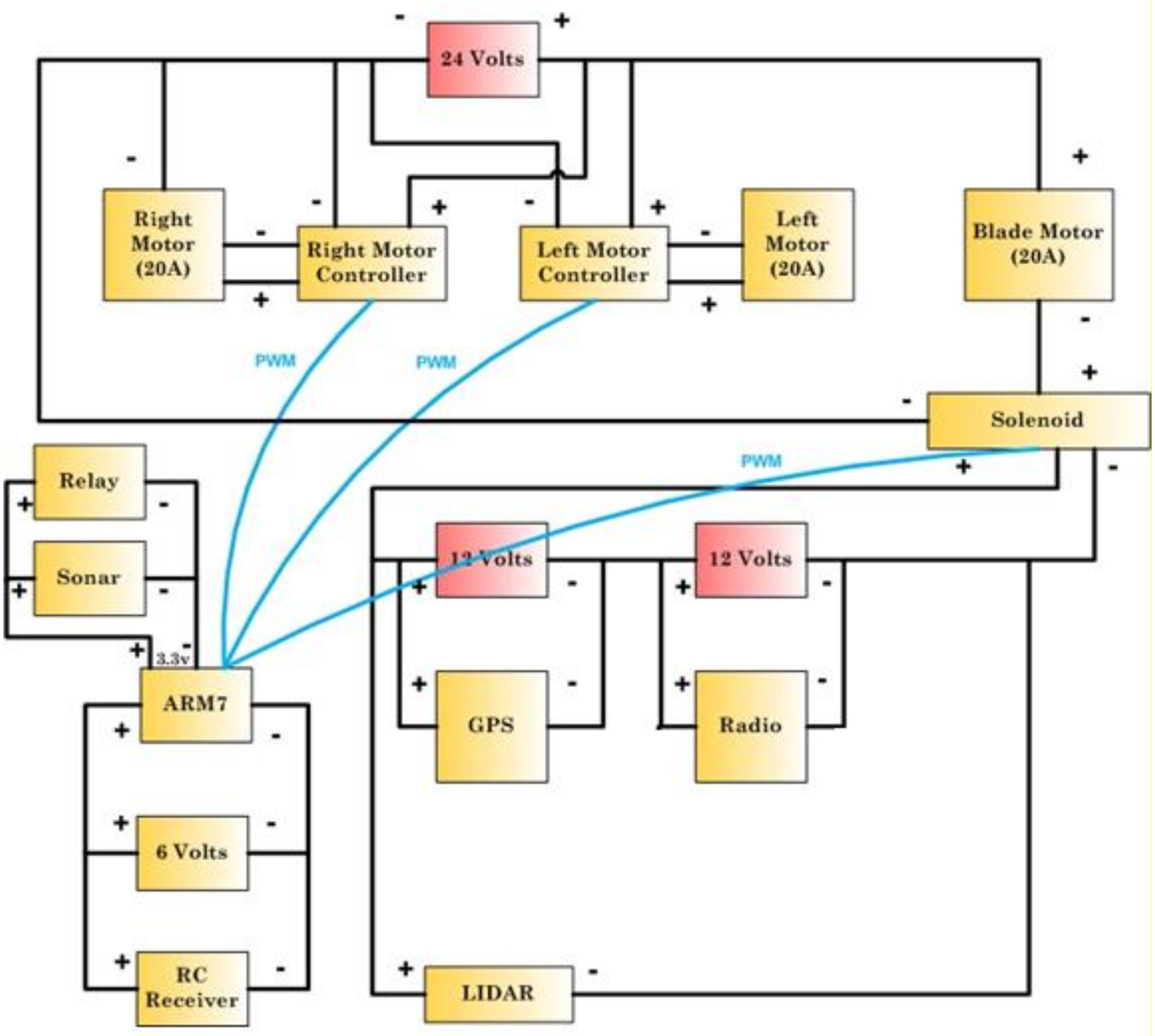
Batteries

We selected the batteries based on the lawnmower's electrical needs. The LIDAR, blade motor, wheel motor, and solenoid required 24 volts. For these, we connected two 12 volt batteries in series to obtain a 24 volt power source. In order to prolong the batteries life, we connected the two 12 batteries in parallel with two more 12 volt batteries which doubled the overall lifespan once the batteries were charged. Next, the

GPS, radio and camera required 12 volts. For these we used two 12 volt batteries. The ARM7 processor required 6 volts and we used a 7806 Voltage Regulator for this. The remote control receiver requires 5 volts to operate, so we used a 7805 Voltage Regulator. Finally, the relay and the sonar rangefinder required 3.3 volts and they received their power supply from the ARM7 protoboard.

Overall Electric System

The diagram below provides a top-level view of the overall electric system.

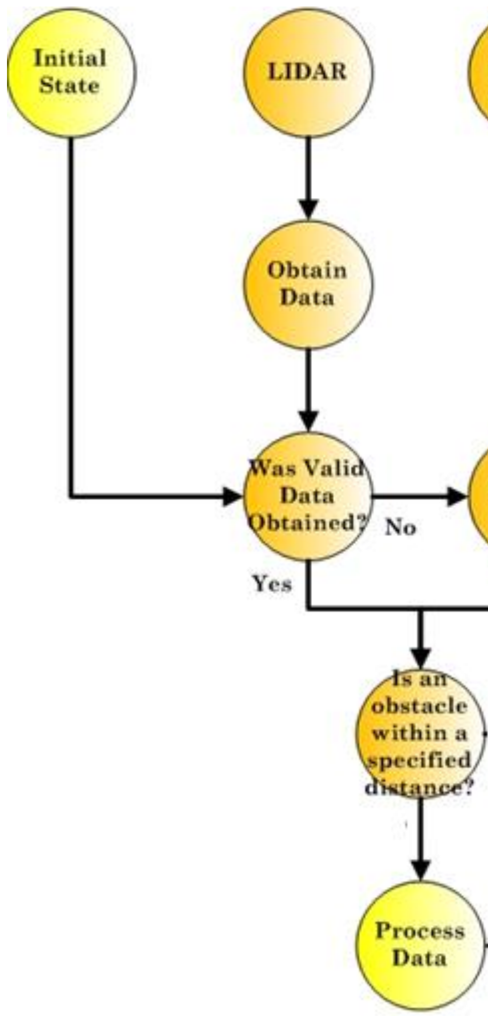


SOFTWARE OVERVIEW

We have designed our lawnmower to participate in the advanced mowing field contest. The advanced competition requires that our lawnmower can detect and avoid two static obstacles (white fence and flower bed) and one moving obstacle (roaming dog). Further, the field will have six sides which can be angled in any configuration. Our mower must remain within the border and cut as much grass as possible without colliding with the obstacles or crossing the border into the out-of-bounds area. The four areas of focus in the software architecture are: obstacle detection, current location detection, path planning, and safety.

Obstacle Detection

Obstacle detection was accomplished by using the Sick LIDAR (primary), the DFRobot URM sonar rangefinder (secondary), a single-instance flowchart of the obstacle detection is as follows:



For each detection instance, data is initially taken from the LIDAR. The LIDAR is programmed to detect obstacles up to 81 meters away with a 0-180 degree range. It scans with single-degree precision and stores the reading from each degree into a finite array in the sick class. The software will process this stored data and verify that the data is valid. Direct sunlight can produce erroneous data so we need to verify that the data is acceptable. If the data is acceptable, the software will determine the position of the object relative to the mower by using the Pythagorean Theorem. Since we know the distance and angle of an obstacle based on the received data, we can calculate the relative position of an obstacle with single-angle accuracy. The equation “**distance** * **cos(angle)**” will let us know how far away the object is on the x-axis the equation “**distance** * **sin(angle)**” will let us know how far away the object is on the y-axis.

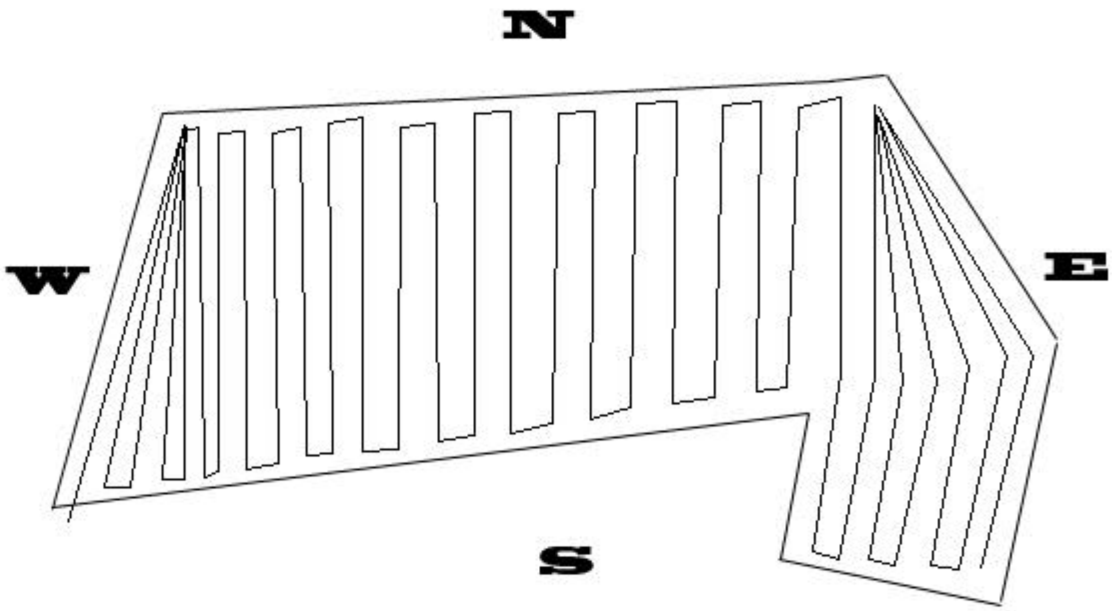
If the LIDAR produces erroneous data due to direct sunlight, the sonar rangefinder is used to detect obstacles instead of the LIDAR. The rangefinder uses sound to determine distance so the sunlight does not affect the rangefinder. Unlike the LIDAR, the sonar rangefinder does not detect object at specific angle. Rather, it detects a certain range that increases in width as the distance away from the device increases. In the case that the rangefinder is used instead of the LIDAR, the data from the rangefinder will determine the distance of an obstacle. Again, if the obstacle is within a certain distance, the camera will take a picture. Then, the histogram from the picture, the whisker data, and the sonar rangefinder data will be sent to data processing. Otherwise, only the sonar rangefinder data and the whisker sensor data will be sent to data processing.

Determine Current Location/Border

In order to determine current position we are using the SF-3050 dGPS device by NavCom Technology, Inc. Before mowing the field, we will visit each corner of the field and record the GPS coordinates of those corners, parse the coordinates, and store them in a file on the main processor (the laptop). When the main program runs it will take the first point (which is to be the desired starting corner) and make it the point of reference. Since the Earth is a sphere and the GPS coordinates are not two-dimensional, it can be very difficult to calculate the location of the GPS for our purpose. However, since the Earth is huge and the field of interest will not exceed 15 meters, we can project the coordinates given by the GPS into a two dimensional plane with a set reference point. For our purposes we also rotated the entire field to fit nicely on the first quadrant. This is done by taking the first point as a reference, and the second point as the next point to be placed on the x-axis. The program will then calculate the rotating angle and rotate every incoming point according to that angle. This helps in debugging because it provides a nicer graph to review. The GPS input is NMEA GPGGA messaging which provides sufficient input data for our equations. The rover reads coordinates at the rate of 10 times per second and these readings are sent to the laptop continuously. However, as the rover moves, the accuracy of these coordinates drift over time. That is where the base unit comes in. Since the base unit remains in the same position, its coordinates are extremely accurate and it sends correction coordinates to the rover at the rate of once per second. By receiving these corrections, the rover is constantly aware of its exact location.

Path Planning

As we considered our path-planning algorithm, we first studied the field for the competition. The border of the field will have specific endpoints but the angles between the endpoints could vary. We decided to write an algorithm that would work regardless of the shape of the field. Our concept of a possible field and the traveled path is shown below:



Potential field and travel lines

We tried to keep the algorithm simple yet effective. Consider the drawing above to have the North/South/East/West directions as shown in the picture and all references in this section refer to the figure. Initially, the mower will start on one side of the field (South-West corner in this case) and it will work its way to the opposite side (East) incrementally. There are two points that set the path for each run: current point and next point. Those points will determine the angle as the lawnmower travels from South to North as well as from North to South. First, it locates the next point and goes in line towards that point. Once it reaches next point, the angle that was initially determined is decreased and it returns to the South side of the field at an angle slightly smaller than the previous angle. The result is that it returns to the South side of the field about 40 centimeters away from the original point. It continues in this fashion until the heading lines are vertically straight. Once the heading lines are vertically straight without an angle it will traverse the field as shown by the center section of the diagram above. The lawnmower continues in this manner until it needs to work with angles again.

The mower will do its best to stay on a shortest-distance path between two points by using the GPS unit. The GPS will calculate a starting point and an end point as the mower goes up and down the field. The algorithm will determine the shortest path between these two points and it will plot a line in which the mower should be on. As the mower travels from North to South (or South to North), the GPS unit will constantly feed coordinates to determine if the mower is on course. If it is within an acceptable range of the desired path it will continue to go straight. However, if the lawnmower strays from path then the algorithm will use the error angle to set it back on course.

In the algorithm we have also included readings from the encoders. If the mower is going in a straight line then the readings from the encoders should match. However, if one wheel spins faster than the other it means that the mower is unintentionally turning. Therefore, in this case, the other wheel will speed up to straighten the mower again. As the mower is correcting itself additional GPS readings will be received aiding the mower in path correction.

Finally, the encoders are used to ensure 90 degree and 180 degree turns when the lawnmower reaches the borders. By counting the ticks in the image we know exactly how much each wheel has turned. Having accurate turns reduces the path-error as the lawnmower changes heading direction.

Safety

With safety being an important aspect we decided to prioritize safety concerns. If the mower enters an unknown state, the mower motors will shut off and the lawnmower will stop. Also, if the software malfunctions, a watchdog timer will trigger and it will also turn off the lawnmower. Finally, the remote control has absolute priority and it will override autonomous control immediately once it is triggered. This way the user will always have the ability to take control of the lawnmower at any given time.

SYSTEM SPECS

Itemized Parts and Cost

Part	Description	Retail	Our Cost
Earthwise 60020	Lawnmower	$269.98	**$269.98**
Pride Jazzy 1470 motors	Wheel Motor	$200.00	**$200.00**
IFI Victor 883 (x2)	Motor Controller	$140.00 each	**$280.00**
T-Slot Aluminum Alloy	Chassis Frame	$300.00	**$300.00**
Lexan	Exterior Covering	$210.00	**$210.00**
NavCom SF-3050 (x2)	dGPS device	Call for pricing	----------
Sick LMS 210 LIDAR	LIDAR	$5,500.00	----------
DFRobot URM V3.2	Sonar Sensor	$26.00	**$26.00**
Aero Sport5	Remote Control	$89.99	**$67.00**
IDEC Corporation HW1B-Y2F01-R	Push-Button	$28.00	**$28.00**
12 volt batteries (x2)	Batteries	$100.00	**$100.00**
12 Volt batteries (x2)	Batteries	Included w/ mower parts	----------
12 Volt batteries (x2)	Batteries	Included w/ trimmers	----------
Olimex LPC-P2148	Microcontroller	$70.00	**$70.00**
Dell Inspiron	Laptop	500.00	---------
Hamamatsu infrared photo reflector (x2)	Phototransistor	$3.25 each	**$6.50**
Misc Parts	Bolts, wires, resistors, etc.	$100.00	**$100.00**
	Total Cost:	**$17680.47 (approximate)**	**$1660.48 (actual)**

Physical Specs

Character	Description
Maximum recommended lawn size	**20meters x 20 meters**
Dimensions	**28 inches (height) x 35 inches (long) x 30 inches (wide)**
Weight	**200 pounds**
Mowing Height	**1 – ½ inches (adjustable)**
Water Resistant	**The lawnmower is water-resistant and it can perform in light rain.**
Environment	**The lawnmower is built to handle a field with low to moderate terrain**
User Interface	**Remote control. Laptop**
Blade Size	**21 inches**
Power Supply	**6 x 12 volt batteries, 4 x AA batteries**
Maximum Run-time	**30 minutes**

Safety Specs

- Remote control which allows the user to override the automation
- Large visible push-button kill-switch located on top of the mower
- Top-of-the-line obstacle sensor (Sick LIDAR) and top-of-the-line GPS unit included for maximum accuracy and reliability
- Watchdog timer implemented to prevent erroneous behavior due to unknown states or malfunction

REQUIREMENTS

No.	Shall Statement	Compliance
1	Team **shall** be comprised of undergraduate and/or graduate students and shall be supervised by at least 1 faculty member	**The team is made up of 4 undergraduate students, namely: Jose Trujillo, David Tran, Bryant To, James Coolidge. The faculty member is Bob Ward**
2	The application form **shall** be submitted by April 21, 2011 with a $200.00 non-refundable registration fee and link to a video of operational lawnmower	**We submitted the application form with the registration fee in a timely manner. The link was submitted a few days later.**
3	The application form **shall** contain an Indemnification Agreement executed by an individual from the team's sponsoring institution who has authority to bind the institution for which he or she signs.	**The Indemnification Agreement was signed Dr. Kenneth James from CSULB Department Chair.**
4	A report **shall** be emailed to Donald T Venable by 5:00 PM on May 12, 2011.	**This report will be emailed before the deadline**
5	Lawnmowers **shall** be autonomous and unmanned and **shall** not be remotely controlled during the competition.	**Our lawnmower is being programmed to cover the field autonomously**
6	Lawnmowers **shall** have a maximum speed of 10 km/hour	**Our lawnmower's maximum speed is below the requirement**
7	Lawnmowers **shall** be equipped with both a manual and a wireless (radio frequency) remote emergency stop capability.	**Our lawnmower has a remote control override as well as an emergency stop button placed on top of the body**
8	The wireless emergency stop **shall** be effective for the entire field of operation plus 10 m in all directions.	**The range of our wireless device is 1 mile. We have tested it up to 1 mile.**

9	The manual emergency stop **shall** be easily accessible by a standing operator behind the lawnmower, and shall be red in color and have a diameter of at least 40 mm.	**Our lawnmower has a red 40 mm pushbutton placed on top of the body.**
10	After the initiation of an emergency stop, the mowing function **shall** cease within 3 seconds and the lawnmower shall be stopped within a distance of 2 m.	**Upon initiation of the emergency stop, our lawnmower ceases within 3 seconds at max speed, and stops within 2 meters**
11	Lawnmowers **shall** not exceed 2 meters in any direction	**Our lawnmower is 0.9 meters by 0.77 meters by 0.69 meters.**
12	Lawnmower movement **shall** be accomplished through direct contact with the ground.	**Our lawnmower's wheels are in direct contact with the ground.**
13	Power **shall** either be provided by combustible fuel, batteries, or both.	**Our lawnmower is powered solely by batteries.**
14	The lawnmowers **shall** demonstrate the ability to mow a predetermined path void of any obstacles.	**We plan to comply with this requirement on competition day**
15	The competitors **shall** be required to start autonomous operation in the safety buffer and mow in the cutting zone.	**We plan to comply with this requirement on competition day**
16	If any part of the lawnmower is outside the safety buffer (2 m in any direction outside the field of operation), the emergency stop **shall** be activated, and the run terminated.	**We plan to comply with this requirement on competition day**
17	The lawnmower **shall** start operation within 5 minutes after the assigned start time.	**We plan to comply with this requirement on competition day**
18	Teams **shall** have a maximum of 20 minutes to cut the field.	**We plan to comply with this requirement on competition day**
19	**The mowers** shall **be designed to operate in any weather condition.**	**Our lawnmower is water-resistant**