ROY

CSULB Autonomous Lawnmower Entry
2010 ION Robotic Lawnmower Competition

Abstract: This year is California State University, Long Beach's first time competing in the ION Robotic Lawnmower Competition and it is our pleasure to introduce our autonomous lawnmower, ROY. ROY was created from the ground up with attention to detail in every aspect. In designing ROY, our primary goal was to build a functional mower that is highly durable, cost efficient, and complies with safety standards and performance requirements while accurately completing the course. The contest rules required our software to be focused in three areas: obstacle detection, path planning, and safety. As each focal point was developed, it was integrated into the overall system of the lawnmower and it is our hope that the students at CSULB can continue to build upon ROY for future competitions. The purpose of this report is to outline each component of our mower in detail.

Martin Armenta, Dawood Putros, Alma Samson

5/14/2010

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2. Introduction

This year is California State University, Long Beach's (CSULB) first time competing in the 2010 ION Robotic Lawnmower Competition. We attempted to assemble a team to compete in 2009 but we were unable to produce a competitive mower at the time. We reassessed the competition in the fall of 2009 and decided that we would work towards producing a worthy mower to compete in the 2010 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. 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. Since this is our first year competing in a robotics competition we spent many hours learning the basics of autonomous robotics, systems integration, and lawnmower construction. Our primary goal was to build a functional mower that complies with the safety standards and performance requirements while accurately completing the course. As of the date that this report is being written, we have been able to accomplish most of our goals although we fell short of implementing a Kalman filter or an IMU. During research for the Kalman filter the team member ended up in the hospital due to a non-school related injury. Moreover, after researching the IMU, the one that we received was defective and the turn-around time to get a working one fell outside of our schedule. Those were the only two major drawbacks. We are still working on adding 2 features which may or may not be completed by the time of competition. Since we are overly ambitious, we believe that these features will be implemented into the lawnmower by the time of the competition. Therefore, it was decided to include them into this report. They are:

1) Add a color camera to determine types of obstacles
2) Add a watchdog timer for safety purposes

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.

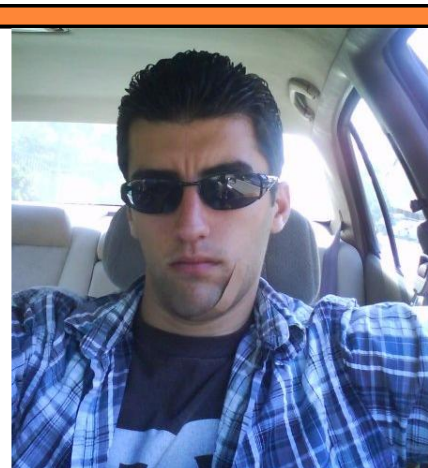
We would like to thank our faculty at CSULB for their support, NavCom Technology, Inc. for their generous sponsorship, and the Institute of Navigation for giving us this autonomous challenge.

Team ROY, 2010

3. Team Overview

The 2009- 2010 CSULB team is composed of the following three students:

:Name:	Dawood "d-woody" Putros
:Area of Study:	BS Computer Engineering, BS Computer Science
:Primary Focus:	unit testing, software development
:Strengths:	Superior work-ethic, dedication, consistency
:Weaknesses:	Pho
:Hours Spent:	400
:Personal Quote:	"I've got my mind on my noodles and my noodles on my mind."

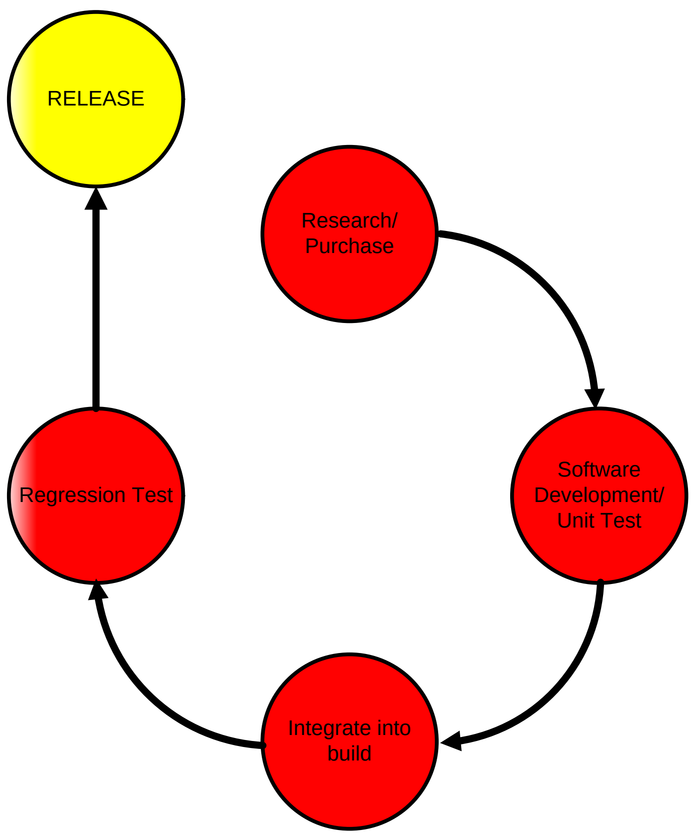


Martin "gramps" Armenta	**:Name:**
BS Computer Engineering, Minor Computer Science	**:Area of Study:**
Research/purchasing, hardware build, documentation	**:Primary Focus:**
Absolute determination, creativity, ambitious	**:Strengths:**
Not a morning person (or an afternoon person)	**:Weaknesses:**
300	**:Hours Spent:**
"Do you know what would be cool?" (followed by an unrealistic idea)	**:Personal Quote:**

:Name:	Alma "the Alminator" Samson
:Area of Study:	BS Computer Engineering, Minor Computer Science
:Primary Focus:	Systems integration
:Strengths:	Able to perform at a very high-level under extreme pressure.
:Weaknesses:	None, zero, zilch
:Hours Spent:	300
:Personal Quote:	"sooooo yeeeeaaahhh....." [insert awkward face]

4. Build Process

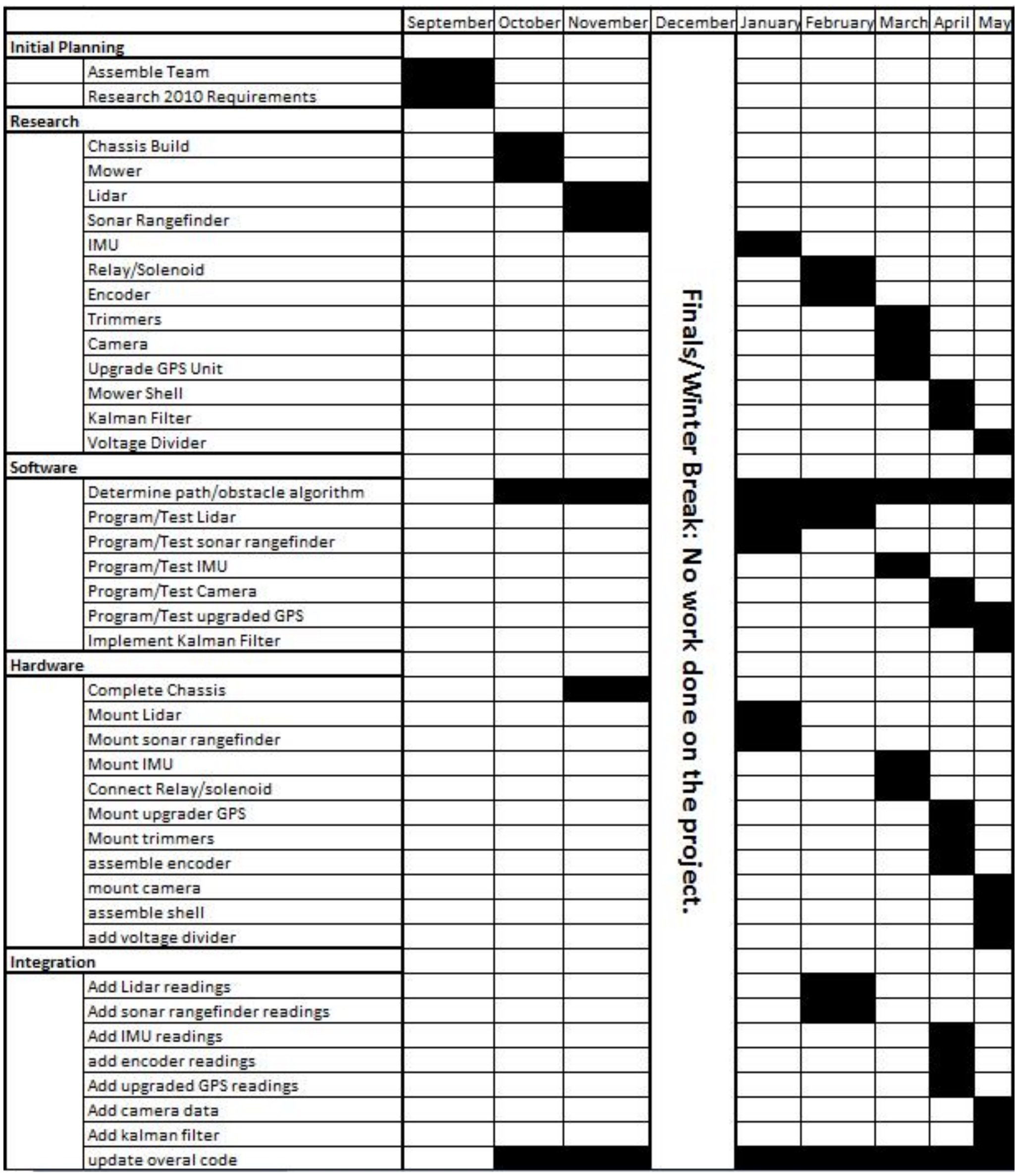
In developing a build plan we considered the dynamics involved with creating a complex autonomous lawnmower. None of our team members have ever taken part in a project of this magnitude so we wanted to pace ourselves in a realistic manner. With only three members we knew that it was essential to plan our time and resources wisely. Moreover, we wanted to build a product that could be passed on to next year's class so we wanted to make sure that each phase of the build process received proper attention. Finally, although we began with lofty goals, we did not know how much progress we could accomplish within our time-span. With this in mind, we decided to focus on building a solid, working model with potential to be improved upon after the necessities were in place. The build process we came up with was an incremental spin-out process. The build process is shown in the diagram below:



Since our lawnmower was built from the ground up in this year's competition, we found it necessary to continuously add to the build starting from the very basics. In this sense, each team member had a primary responsibility within the build Martin was chosen to do the research and to make the final purchases after the team agreed upon components. If the element was part of the robot's body, Martin was in charge of adding it to the body. If the element was a programmable component, Dawood was chosen to learn how to program it, understand its capabilities and weaknesses, and perform the unit tests. Once our team figured out how to implement the devices, Alma was in charge of integrating it into the overall build. Finally, we worked together to run regression tests before considering the new build a “release”. For the most part we tried to remain loyal to this process although at times the duties would swap due to necessity.

5. 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 IMU implementation).



6. 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 and a powerful LIDAR. Both of 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." For this year's competition we will rely heavily upon the LIDAR but next year we will attempt to configure a less-expensive detection device. 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.

7. 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

7.1 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) A relay and a solenoid so that the moving components could stop immediately when necessary.
e) Low maximum speed

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

7.2 Accurately traverse a field autonomously

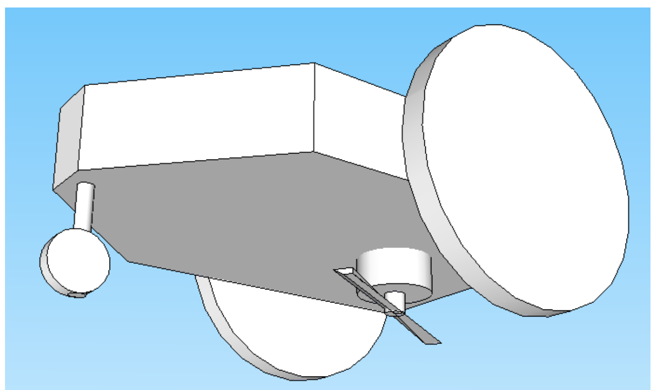
The accuracy of our mower was of utmost importance in our design concept. When a human mows a lawn he/she is constantly aware of the surroundings and we knew that our lawnmower would need to imitate the same awareness. In order to obtain this awareness we would need to know details such as current position, 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.

7.3 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 section 8.1(a). 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.

7.4 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:



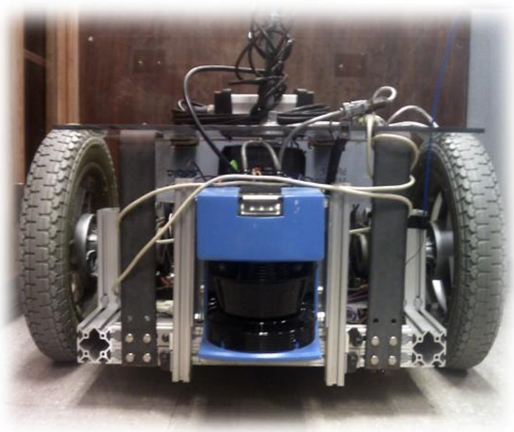
As you can see, the blade was intended to cover the length of the chassis. Moreover, we wanted to have the ability to do zero-degree turns so we opted to use two driving wheels with differential drive and one trailing wheel for balance. The zero degree turn would allow us to have better control around 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. Since a significant percentage of the score is based on the area near the obstacles we decided that it would be necessary to include a string trimmer near the rear edge of the mower. By adding the string trimmer we are able to get a closer cut to the flower bed, fence, and the border of the field.

7.5 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. Although this year's entry only has one element developed by our team (the encoders) it is our hope that next year's entry will continue to replace high-cost parts with greater innovation, increased "intelligence" of the mower, and student-manufactured components.

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



Front View

Side View

8. Hardware Overview

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

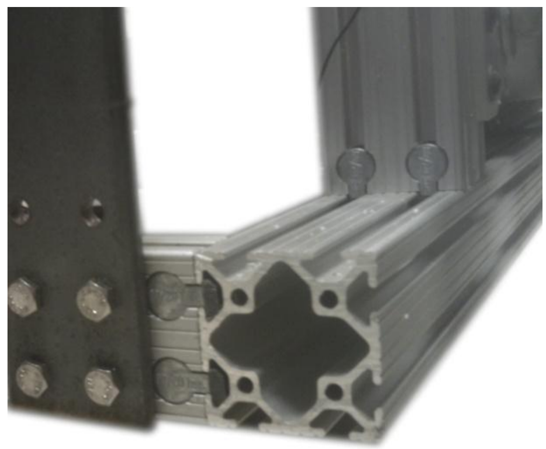
1) Mechanical (Section 8.1)
2) Electrical (Section 8.2)

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.

8.1 Mechanical

8.1(a) Chassis

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



As mentioned in section 7.3, 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.

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.

8.1(b) 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.

8.1(c) 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

8.1(d) 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.

8.1(e) String Trimmer

Specifications	
Product	B&D CST800
Cost	$69.99
Purchased from	Amazon.com
Input Voltage	12 Volts
Cutting Path	8 inches
RPM	8500 rpm
Feed System	bump
Application	Cuts grass

When we were considering the trimmers we only had one concern. Traditional trimmers require a user to tap the head on the ground when the line would wear out due to use. The alternative is to use a self-feeding trimmer which "should" automatically feed itself when the trim is cut so that the trim is always at an ideal length. It would appear that the obvious choice would be to use the auto-feed trimmer. However, according to the reviews, the auto-feed trimmers available aren't reliable as the trim-control can break causing the trim to keep feeding until it is beyond the desired length. Since we prioritized safety over performance we decided to stick with the manual feed trimmer. The trimmer we selected is the Black & Decker CST800 8 inch 12 volt electric trimmer. Considering the fact that the trim cannot be fed again once it breaks we decided to only run the trimmer when it is edging an obstacle or the border of the field. A future enhancement would be to create our own auto-feed system that is reliable and safe.

8.2 Electrical

8.2(a) 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.

8.2(b) Sensors

8.2(b1) 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.

8.2(b2) 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 "hat" on top of

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)

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).

8.2(b3) Sonar Rangefinder

Specifications	
Product	Maxbotix LV-EZ1
Cost	$26.00 each (x2)
Purchased from	Sparkfun Electronics
Input Voltage	2.5-5.5 Volts
Range	6-254 inches
Sensor	42Khz ultrasonic
Reading rate	20Hz
Application	Obstacle detection (secondary)

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 Maxbotix 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.

8.2(b4) Color Camera

Specifications	
Product	Unibrain Fire-I 1394 Color Camera
Cost	$240.00
Purchased from	The1394Store.com
Input Voltage	12 Volts
Speed	400 Mbps
Scanning	Progressive
Pixels	659x494
Max frame rate	30 fps
Application	Determine obstacle type based on color

Although the LIDAR is capable of detecting obstacles, we wanted the lawnmower to have the ability to differentiate the various obstacles. Since the border of the flower bed is black and the fence is white, we figured that adding a color camera would help us determine if an obstacle was something to be avoided (flower bed, fence) or if it was something to be ignored (high grass). The Unibrain camera is able to take snapshots and convert the pictures into histogram readings. Based on the color balance in the histogram we are able to determine which obstacle is directly in front of the lawnmower. This information helps the lawnmower to determine a course of actions based on the information. At the time of this report we are still testing this device for implementation. However, we assume that the camera's reading will be increasingly saturated with black as it approaches the flower bed and increasingly saturated with white as it approaches the fence. We may also use the camera to detect the border of the field as well since the border will have a white line but that is still to be determined.

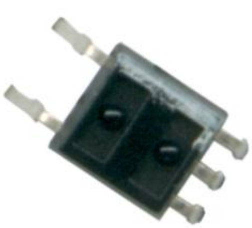
8.2(b5) Whisker Sensors

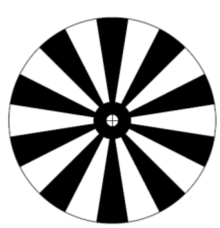
During testing we realized that our lawnmower has a potential "blind spot" near the front corners which are slightly out of the LIDAR' view. We decided to add a whisker sensor in order to detect an object that is in this "blind spot". The whisker sensor is a touch-sensor in which the tip of the whisker will trigger a signal to the computer if comes into contact with an object. Similar to whiskers on a cat, the tip of the whisker sensor is sensitive to very light stimuli. The whisker's slightest contact with an object will cause the lawnmower to take a responsive action. This sensor allows us to mow close to obstacles while maintaining a safe distance from the object.

Specifications	
Product	Whisker Sensors
Cost	$10.00
Purchased from	Lynxmotion
Range	1 foot
Application	Obstacle detection (touch)

8.2(b6) Encoders

Specifications	
Product	CSULB Smart Spin
Cost for Parts	$5.00 each (x2)
Input Voltage	5 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 #P5587) 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.

8.2(c) Motor Controllers

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.

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

8.2(d) Remote Control

Specifications	
Product	Cirrus 2Cam Remote Control
Cost	$30.00
Purchased From	Hobby People
Max Distance	Approx 25 meters
Operating Frequency	AM 27MHz
Application	Drive the mower manually

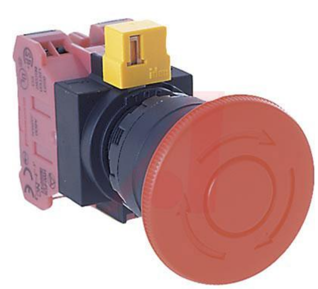
Although the lawnmower is fully autonomous, we have a remote control feature which allows a user to interface directly with the mower. This remote control has priority in the software so it will override the lawnmower if it is operating in autonomous mode. We selected a remote control that has both sufficient range and excellent control. The Cirrus 2Cam remote control that we selected has a range of ¼ a city block (approx 25 meters) and it has two sources of control: one being the trigger and the other being the spinning wheel on the side of the controller. We used one of these controls for direction and the other for throttle. 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.

8.2(e) Push-Button Emergency Stop

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.

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



8.2(f) 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, trimmer and camera required 12 volts. For these we used two 12 volt batteries. The ARM7 processor and remote-control receiver required 6 volts and we used 6 AA batteries for these. Finally, the relay and the sonar rangefinder required 3.3 volts and they received their power supply from the ARM7 protoboard.

8.2(g) Relay

Specifications	
Product	Crouzet 84137180
Cost	$56.00
Purchased From	Octopart
Current Rating	30 Amps
Input Voltage	3.3 Volts
Application	Controls the trimmer

We implemented a solid state relay into the lawnmower which enables us to turn the string trimmer on or off via an output signal from the microprocessor. The solid state relay acts as a switch. If it receives a high signal from the ARM7 processor, it will allow current to flow essentially turning on the trimmer. On the other hand, if it receives a low signal, it cuts off the current turning off the motor. We selected the Crouzet 84137180 as it works with minimal power and efficiently does the required task of trimmer control.

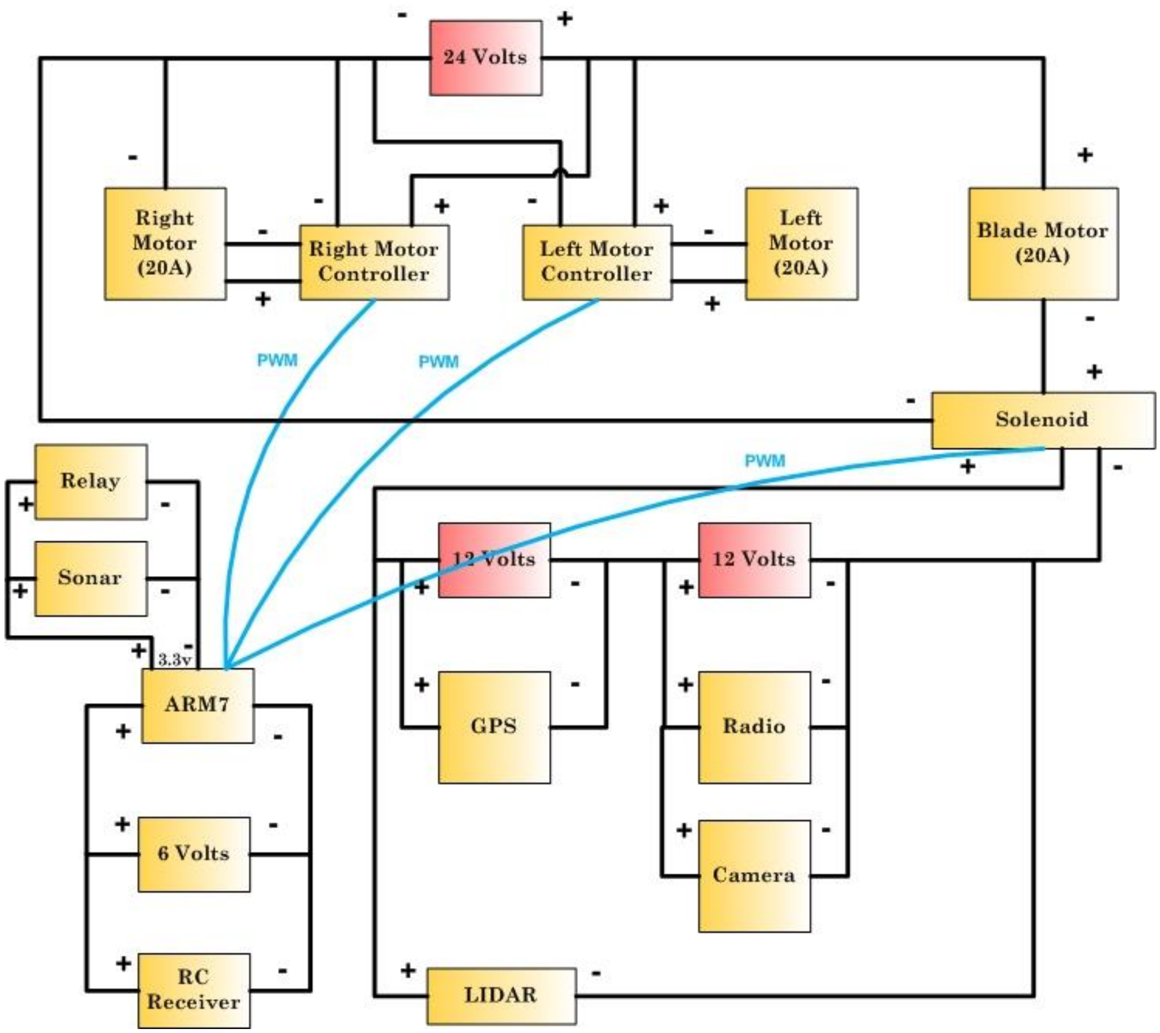
8.2(h) Solenoid

Similar to the relay, we also wanted to have the ability to control the blade motor via an input signal. Since the blade motor requires higher amps, we decided to use a solenoid. The solenoid that we selected can handles 200 amps continuous with the ability to handle 600 amps within the first ½ second of contact closure. Initially we tried to use a relay and it burned out. However, this solenoid works extremely well with our lawnmower.

Specifications	
Product	White Rodgers 586-905
Cost	$100.00
Purchased From	Team Delta
Current Rating	200 Amps
Input Voltage	24 Volts
Application	Controls the blade motor

8.2(i) Overall Electric System

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

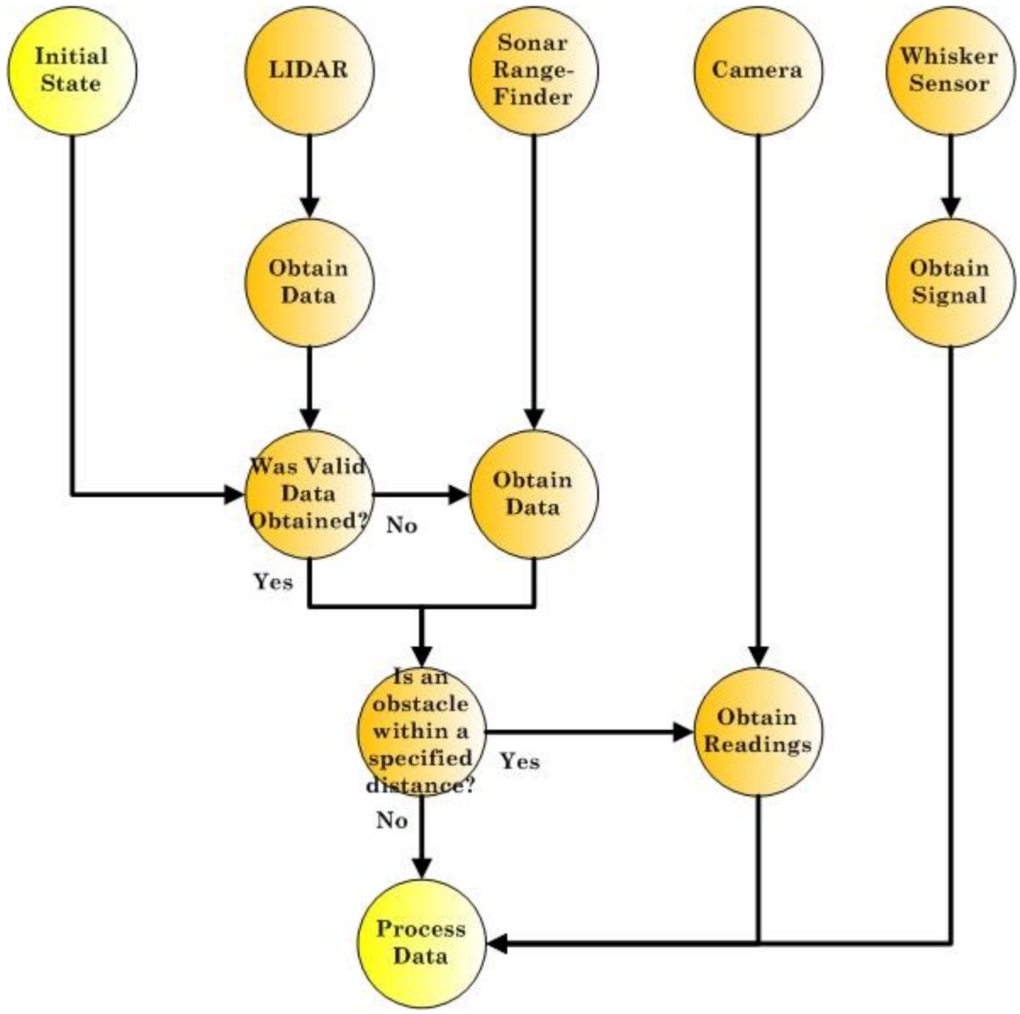


9. Software Overview

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.

9.1 Obstacle Detection

Obstacle detection was accomplished by using the Sick LIDAR (primary), the Maxbotix sonar rangefinder (secondary), the color camera (complementary), and the whisker sensors (proximity restrictiveness). A single-instance flowchart of the obstacle detection is as follows:



For each detection instance, data is initially taken from both the LIDAR and the whisker sensor. 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 object is within a specified distance (to be determined) the camera will take a picture to obtain a histogram and send the histogram data, the LIDAR data, and the whisker data to data processing. Otherwise, only the LIDAR data and the whisker sensor data is sent to data processing for speed control and obstacle update.

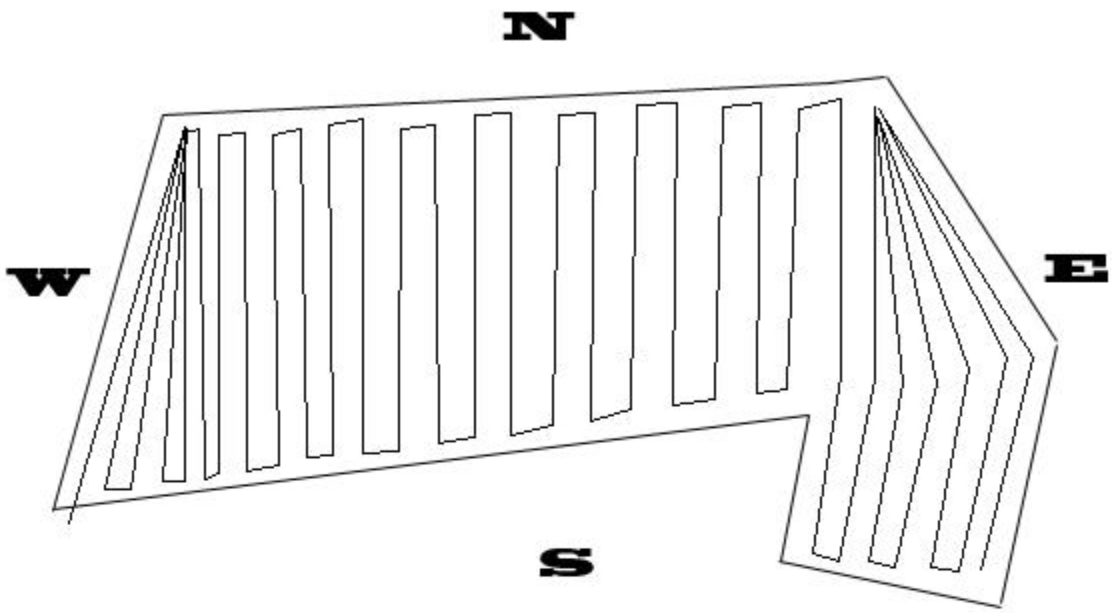
If the LIDAR produces erroneous data due to direct sunlight, the sonar rangefinder is used to detect obstacles instead of the LIDAR. The rangefinder uses sound to determine distance so the sunlight does not affect the rangefinder. Unlike the LIDAR, the sonar rangefinder does not detect object at specific 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.

9.2 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.

9.3 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.

9.4 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.

10. System Specs

10.1 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	----------
Maxbotix LV-EZ1	Sonar Rangefinder	$26.00	$26.00
Unibrain Fire-I 1394 Color Camera	Color Camera w/accessories	$240.00	$240.00
Whisker Sensor	Touch Sensor	$10.00	$10.00
Crouzet relay (GN84137870)	Relay	$50.00	$50.00
White Rodgers 586-905	Solenoid	$100.00	$100.00
Cirrus 2Cam	Remote Control	$30.00	$30.00
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
Compaq Presario V5000	Laptop	320.00	$320.00
Hamamatsu infrared photo reflector (x2)	Phototransistor	$3.25 each	$6.50
Misc Parts	Bolts, wires, resistors, etc.	$100.00	$100.00
Black and Decker CST800	String Trimmer	$69.99	$69.99
	Total Cost:	**$27.410.47 (approximate)**	**$2,410.47 (actual)**

10.2 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 build 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

10.3 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

11. 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 3 undergraduate students, namely: Dawood Putros, Martin Armenta, and Alma Samson. The faculty member is Bob Ward
2	The application form **shall** be submitted by April 16, 2010 with a $200.00 non-refundable registration fee	We submitted the application form with the registration fee in a timely manner
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 by Cathy Bishop, Buyer III from CSULB purchasing department.
4	A report **shall** be emailed to Donald T Venable by 5:00 PM on May 13, 2010.	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 25. We have tested it up to 25 meters
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 (however, it is not water-proof).