2011 Annual ION Robotic Lawn Mower Competition

University of Michigan – Dearborn

Autonomous Grass Muncher

Intelligent Systems Club

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1 Introduction

The Intelligent Systems Club at the University of Michigan - Dearborn set out to design a vehicle which would be capable of mowing a given area of grass without requiring human interaction. The team aims to compete, and win, with the vehicle at the 8th annual Institute of Navigation Robotic Lawnmower Competition in June 2011. For the competition, as well as general safety reasons, the vehicle must be capable of avoiding obstacles while mowing is taking place in autonomous mode. One of the most significant objectives of the team is to experience interfacing with raw sensors and their data, as well as coming up with control methods and navigational algorithms to effectively operate a robot of this nature.

The Intelligent Systems Club is made up from mostly senior level undergraduates in electrical and computer engineering. Participation in the club is voluntary and extra curricular; no class credits are earned for participation and all work is completed on the students time between balancing work and class schedules. For this project, the following members were involved:

- Michael Pearson, Computer Engineering: Navigation and Software
- Kristopher Bechamp, Computer Engineering: Navigation and Software
- Mark Lawrence, Electrical Engineering: Chassis and Electrical
- Tuo Xiang, Electrical Engineering: GPS and IMU
- Mel Malabanan, Electrical Engineering
- Eileen Radzwion, Computer Engineering
- Zakaria Juber, Electrical Engineering
- Jayavardhan Tallapragada, Mechanical Engineering
- Srivardhan Tallapragada, Mechanical Engineering
- Nattu Natarajan, Associate Professor: Advisor

The project, codenamed AGM for Autonomous Grass Muncher, began a month or two prior to the 2011 ION Robotic Lawnmower Competition. The team worked hard to get a worthy robot together to compete, and it has now evolved into a complete lawn-mowing system. The Munchers main chassis consists of square steel tubing which was used to mount a store-purchased electric lawnmower. Two 24V power wheelchair motors are used to propel the robot using differential steering. A combination of sensors including wheel encoders, GPS, an inertial measurement unit (IMU), ultrasonic range sensors, and a camera are used to allow the robot to learn about its surroundings and to provide navigational aid. In the simplest sense, the robot will break the field down into reasonably sized blocks. The GPS coordinates of at least two, but preferably all four corners, must be known. The center of each of block will be considered a waypoint, and the robot will attempt to navigate through each waypoint while staying within the boundaries. The encoders paired with the IMU will aid the robot in making its turns. If and when an obstacle is detected by either the vision or ultrasonic range sensors, the robot will enter an avoidance mode during which it will maintain a safe distance from the obstacle while attempting to make its way to the next desired waypoint. Once all waypoints have been traversed, the robot will return to the origin and attempt another pass.

The navigation system is comprised of a GPS unit, an IMU, and wheel encoders to aid the robot in traversing the course. The GPS will use the predetermined corner coordinates of the plot to construct a map of the mowing field. Upon start up, the GPS will communicate with available satellites to determine the robots location and map the competition field. The wheel encoders and the IMU will be used in conjunction to estimate the distance traveled as a means to stay in bounds. The wheel encoders are the primary navigation aid while the GPS and the IMU are used as augmentation to correct for slip errors in the encoder data when traction is lost. The IMU and encoder will also be used for making accurate turns, the encoders for measuring how far one wheel must turn for AGM to rotate a desired degree amount, and the IMU's magnetometer for measuring change in yaw.

AGM's obstacle avoidance system consists of ultrasonic range sensors and an off the shelf web-cam. The ultrasonic range sensors will be setup on the robot to avoid obstacles in front of and to the side of the robot. The robot will also be aided in obstacle avoidance through the use of the web-cam. In addition to detecting obstacles, the web-cam has a dual purpose of assisting the robot to stay in bounds by detecting the field boundary and treating it as an obstacle that the robot will avoid, thus staying within the boundaries.

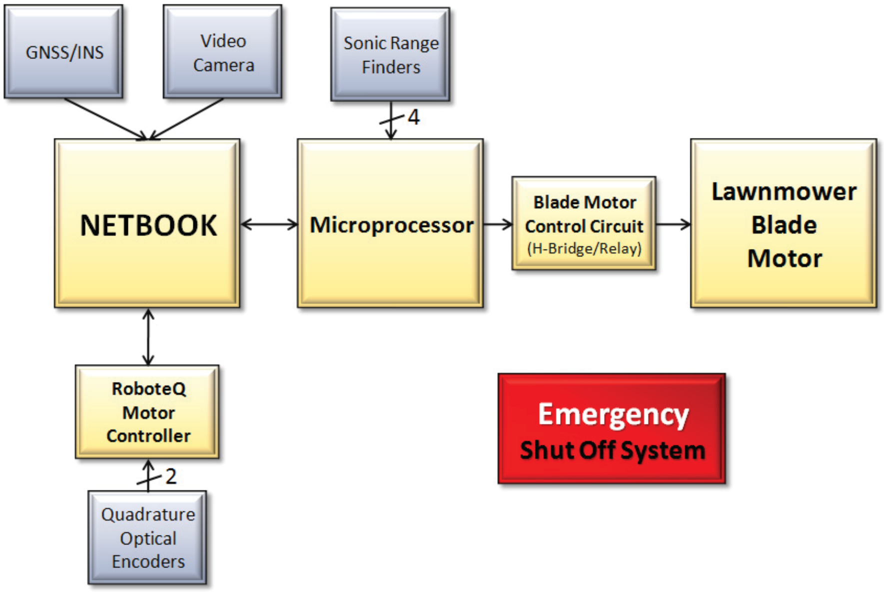

Figure 1: The Autonomous Grass Muncher systems overview.

A mechanical system including the chassis and drive system was designed. The chassis was produced in house and designed around a store purchased lawnmower. The lawnmower was dismantled and mounted to the chassis, maintaining most of the core components minus the wheels, push bar, and starting mechanism. A carrier was created to house the batteries over the rear drive axles to allow the added weight to increase downward force and thus improve traction. Navigation sensors are located above the mower for line of sight reasons (satellites), obstacle avoidance sensors are located around the front and sides of the mower to provide an adequate safe maneuvering radius, and the vision camera is mounted above the front of the mower to provide a forward facing downward point of view. Figure 1 shows the high level design of the overall system.

2 Systems Introduction

The safety system is made up primarily of two emergency kill switches, one physical and one wireless remote switch. The physical emergency stop is located at the rear of the robot such that a person who needs to cut power and disable the robot shall be following the robot rather than being chased by the robot. It shall also be located approximately three feet high so that a person can comfortably and safely activate the shutoff while walking behind the robot. In the event that the robot is out of reach, a wireless remote emergency switch can be activated from a distance and perform the same function, that is to cut the main power from the robot and disengage the motors and the mowing function.

AGM's software has been written in the C programming language and developed in the Linux environment. The software has been developed in a multi-threaded fashion using the POSIX PThreads library such that obstacle avoidance has its own thread which will take precedence given certain circumstances and the remaining processes all run on a separate main thread. A Microchip PIC16 microprocessor receives the analog signal output by the ultrasonic range sensors and converts it to a digital signal usable by the netbook. The web-cam, wheel encoders, IMU, and GPS all communicate directly with the netbook which handles all of the calculations and image processing and sends commands to the motor controller to determine the action the robot is to take.

The University of Michigan - Dearborn is poised to place well in this competition after learning from the lessons of last year. A newly redesigned platform has been developed that is far more robust and maneuverable in this off-road environment. More time has been spent on developing sensor interfaces and precautions have been made to protect the sensors. This year the control scheme has been improved and analyzed and the team is confident in its implementation. The waypoint guidance plan should allow this vehicle to complete its grooming of the competition field in an effective and clean manner. This year the vehicle is primarily relying on optical wheel encoders with correction from alternate sensors opposed to last year when the teams navigation system was developed around an inaccurate GPS module and an electronic compass that failed to work during the competition. Safety has been stressed in every step in the design, from speed governing to an emergency shutoff system. All students on the team agree that this has been an exciting educational experience and by using the lessons learned by last years competition, the team is ready to compete.

3 Requirements

TYPE	REQUIREMENT	REASONING
Positional Accuracy	1 meter	To ensure the mower stays inside the field
Sampling Rate	5Hz or better	In order to maintain accuracy
Control	10Hz or better	To ensure tight control
Velocity	≈ 1.5 m/s	Safe, yet reasonable speed
Weight	< 300 lbs	Must be light enough to be lifted by team for travel
Horsepower	> 3.5 HP	3.5 HP required to move 300lb at 2 m/s
Robot width	< 36 in	Must fit through a standard doorway

4 Mowing Strategy

The strategy for mowing the field is as follows:

1. Divide the field into a rectangular grid.
2. Determine a path that goes through the grid points in some specified order. To maximize the amount of grass cut before accidentally going out of bounds, the path consists of moving to the center of the field and working outward along a spiral and once the all the grid points have been visited, the path spirals in towards the center.
3. Prior to competition the path may be modified to make attractive patterns for the best cut prize.

This method was selected to both lower the chance of boundary encroachments and increase the coverage of the competition field.

5 Robot Guidance and Control

The basic guidance and control problem is to navigate to a chosen waypoint. To achieve this, at every instant of time, the following information is assumed to be known about the robot:

$$\begin{aligned} N_R &= \text{North-south coordinate of the robot in meters} \\ E_R &= \text{East-west coordinate of the robot in meters} \\ \theta &= \text{Robot heading measured from North} \end{aligned}$$

The desired waypoint is given by

$$\begin{aligned} N_T &= \text{North-south coordinate of the target waypoint in meters} \\ E_T &= \text{East-west coordinate of the target waypoint in meters} \end{aligned}$$

The robot is controlled using differential steering which independently controls the left and right wheel speeds. Thus, the control variables are

$$\begin{aligned} S_L &= \text{Left wheel speed in m/s} \\ S_R &= \text{Right wheel speed in m/s} \end{aligned}$$

5.1 Dynamics

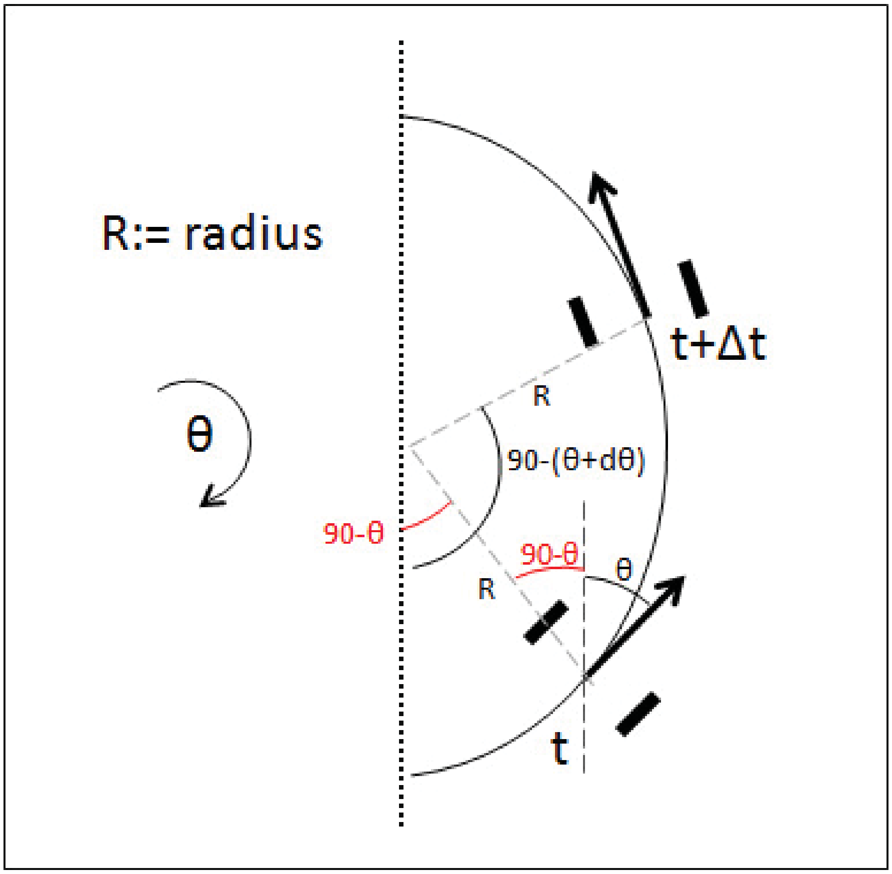

Figure 2: Basic Geometry of differential steering. In this figure, the right wheel turns faster than the left wheel causing the robot to turn counter clockwise. Note that heading is measured clockwise.

The equation of motion in terms of the individual wheel speeds can be derived from the figure 2. From the figure, as the robot moves through an arc $d\theta$ the left wheel moves along an arc of radius $R - L/2$ and the right wheel moves along an arc of radius $R + L/2$. Hence,

$$(R - L/2)\frac{d\theta}{dt} = -S_L \tag{1}$$

$$(R + L/2)\frac{d\theta}{dt} = -S_R \tag{2}$$

Adding and subtracting

$$\begin{aligned} -R\frac{d\theta}{dt} &= \frac{S_L + S_R}{2} \\ &= S \ \text{ Robot's speed} \qquad (3) \\ \frac{d\theta}{dt} &= \frac{S_L - S_R}{L} \qquad (4) \end{aligned}$$

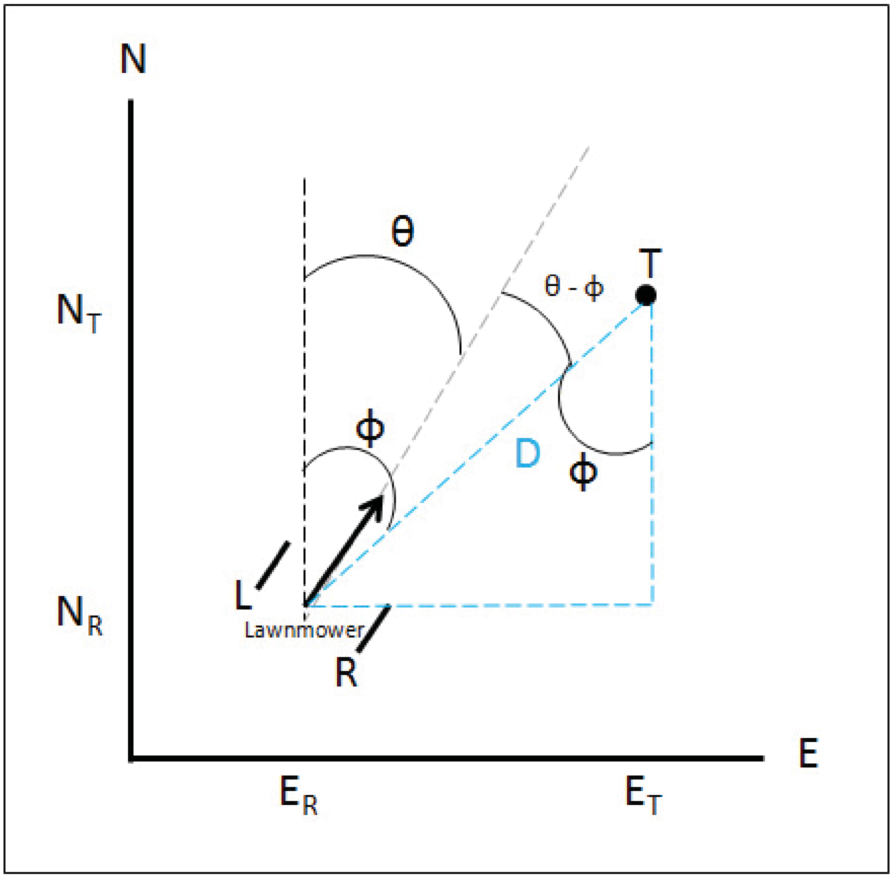

Figure 3: Way point navigation. The guidance is determined primarily by the difference between the bearing of the target waypoint and the heading of the robot. The object of the control is to make the difference, relative bearing $\mu = \phi - \theta$, zero.

The motion of the robot can be derived using figure 3 as follows: Let Δ_N and Δ_E denote the target's location with reference to the robot, i.e.

$$\Delta_N = N_T - N_R \quad (5)$$

$$\Delta_E = E_T - E_R \quad (6)$$

Let D be the distance to the target

$$D = \sqrt{(\Delta_N)^2 + (\Delta_E)^2} \quad (7)$$

Let ϕ denote the absolute bearing of the target. Let the relative bearing of the target be μ. From figure 3

$$D \cos\phi = \Delta_N \quad (8)$$

$$D \sin\phi = \Delta_E \quad (9)$$

$$\mu = \phi - \theta \quad (10)$$

Differentiating (8) and (9) with respect to t

$$\begin{aligned}
\frac{dD}{dt}\cos\phi - D\sin\phi\frac{d\phi}{dt} &= \frac{d\Delta_N}{dt} &(11)\\
\frac{dD}{dt}\sin\phi + D\cos\phi\frac{d\phi}{dt} &= \frac{d\Delta_E}{dt} &(12)
\end{aligned}$$

There are two unknowns in the two derivatives. Solving the system provides

$$\begin{aligned}
D\frac{d\phi}{dt} &= \frac{d\Delta_E}{dt}\cos(\phi) - \frac{d\Delta_N}{dt}\sin\phi &(13)\\
\frac{dD}{dt} &= \frac{d\Delta_N}{dt}\cos(\phi) + \frac{d\Delta_E}{dt}\sin\phi &(14)
\end{aligned}$$

Since the target is stationary,

$$\begin{aligned}
\frac{d\Delta_N}{dt} &= -\frac{dN_R}{dt} = -S\cos\theta &(15)\\
\frac{d\Delta_E}{dt} &= -\frac{dE_R}{dt} = -S\sin\theta &(16)
\end{aligned}$$

Substituting

$$\begin{aligned}
D\frac{d\phi}{dt} &= -S\sin\theta\cos(\phi) + S\cos\theta\sin\phi\\
&= S\sin\mu &(17)\\
\frac{dD}{dt} &= -S\cos\theta\cos(\phi) - S\sin\theta\sin\phi\\
&= -S\cos\mu &(18)
\end{aligned}$$

Finally, the relative bearing satisfies

$$\begin{aligned}
\frac{d\mu}{dt} &= \frac{d\phi}{dt} - \frac{d\theta}{dt}\\
&= \frac{S}{D}\sin\mu - \frac{d\theta}{dt} &(19)
\end{aligned}$$

The open-loop state space formulation for the system with S, $\frac{d\theta}{dt}$ as the input is given by

$$\begin{aligned}
\frac{dD}{dt} &= -S\cos\mu &(20)\\
\frac{d\mu}{dt} &= \frac{S}{D}\sin\mu - \frac{d\theta}{dt} &(21)
\end{aligned}$$

Note that the system is nonlinear. The object of the control is to make $D \to 0$ and $\mu \to 0$.

5.2 Control

Control consists of two parts. First is the speed control. To maintain a smooth motion, the speed decrease as the robot approaches the target. However, it should be noted that in the actual implementation, once the robot gets close to a target waypoint, the target will be changed to the next grid point in the desired path. The speed S is chosen as

$$S = g_1 D \tag{22}$$

where g_1 is a positive constant of proportionality. To ensure that $\mu \to 0$, set

$$\frac{d\theta}{dt} = g_2 \sin\mu \tag{23}$$

where $g_2 > g_1$. Thus the closed loop state space model for the system is given by

$$\begin{aligned} \frac{dD}{dt} &= -g_1 D \cos\mu && (24) \\ \frac{d\mu}{dt} &= (g_1 - g_2)\sin\mu && (25) \end{aligned}$$

This is a non-linear system. For small μ it is sufficient to linearly approximate $\cos\mu \approx 1$ and $\sin\mu \approx \mu$ to get a linearized model

$$\begin{aligned} \frac{dD}{dt} &= -g_1 D && (26) \\ \frac{d\mu}{dt} &= (g_1 - g_2)\mu && (27) \end{aligned}$$

This represents a decoupled system with poles at $-g_1$ and $g_1 - g_2$. Since $g_1 > 0$ and $g_2 > g_1$ both the poles are negative, thus indicating stable behavior.

5.3 Implementation

The individual wheel speeds can be computed from (22), (23), (3) and (4) provides

$$\begin{aligned} \frac{S_L + S_R}{2} &= g_1 D \\ \frac{S_L - S_R}{L} &= g_2 \sin\mu \end{aligned}$$

Solving

$$\begin{aligned} S_L &= g_1 D + \frac{1}{2} L g_2 \sin\mu \\ S_R &= g_1 D - \frac{1}{2} L g_2 \sin\mu \end{aligned}$$

In the actual implementation, several additional constraints are placed on the control. If the speed of the wheels exceed the maximum allowable speed of the robot, then both the speeds are scaled down proportionately. If $\cos\mu$ is less than zero, then the target will be behind the robot. In this case, the robot turns in place till the target is in front of the robot. If one of the wheel speeds is negative, the robot may potentially lose traction on wet grass. To prevent this, set any negative speeds to zero. This occurs when

$$g_1 D < \frac{1}{2} L g_2 \sin|\mu| \tag{28}$$

This typically means that the robot is close to the target and the relative bearing is large, i.e the robot has to make a sharp turn in place. This is handled as a special case in the control algorithm.

6 Navigation

A navigation system is a method of determining the position and course of a vehicle through the use of geometric description and a navigation technique (Groves 3), also known as the *art* and the *science* of navigation. A navigation technique is defined as a method of determining a vehicles position and velocity. The model developed for this navigation system uses three navigational aids to provide the system parameters. It includes one positioning sensor, the dGPS, and two tracking sensors, the IMU and quadrature phase optical encoders. A positioning sensor is a sensor that determines the physical position of an object with respect to a larger reference. In this case the location of the lawnmower with respect to the earth is measured. A tracking sensor is one that measures kinematic properties of an object.The output of the navigation system is the navigation solution; which is a vector that provides the body frame referenced kinematic state of the vehicle.

The lawnmower navigation system has been organized into three separate modules. Vehicle localization is accomplished in one module and obstacle detection is in another. The third module is the drive control system that has as its input a velocity command and as its output a pulse width signal that drives the lawnmowers motors. The two high-level modules operate in tandem with one another. When the obstacle avoidance module identifies an encroaching landmark it takes control of the system. In this case the system transitions into the obstacle avoidance mode until it can safely return to the initial path. Therefore, path recovery must be implemented in the obstacle avoidance routine, increasing the need for shared localization data.

The objectives of the navigation system are to provide the lawnmower with accurate localization information relating its perceived position to the actual position within the competition field. The navigation system has the additional objective of identifying obstacles and actively avoiding them with the requirement of staying within the boundaries of the field.

The overall system design consists of several sources of geographic and kinematic information. The sources include a differential global positioning system (dGPS), an inertial measurement unit (IMU), and two quadrature optical encoder units. Geographic information is provided by the latitudinal and longitudinal identifiers in the output of the dGPS and also in the dead-reckoning position estimates from the encoders. Kinematic information can be resolved from all three sources. Important kinematic information for this application include: heading / course, instantaneous velocity, instantaneous acceleration, average velocity and average acceleration. Heading is resolved from all three sources. The dGPS provides a rough course estimate that is determined by the change in position of the vehicle. The IMU that was chosen for this navigation system provides several course measurements; gyroscopic acceleration provides a yaw angle that is used recursively to estimate the vehicles heading. The IMU houses a magnetometer that gives a heading reference in the same way that a compass would provide. Also, heading is deduced by the position data provided by the encoders. Using these parameters, a pool of raw positional and kinematic data can be fed through a filter to provide probabilistically optimal data that can be used to generate the proper vehicle drive commands to pass to the motor controller.

The primary system as described above relies on several sensor sources. This requires that similar data from the several sources be fused into one statistically optimal parameter. The method chosen to do this is based upon a Kalman filter algorithm used in several other projects by students of the university. Through this optimizing procedure the team intends on obtaining positional and kinematic data that can be used to successfully navigate the competition field.

6.1 Backup Navigation Plan

A backup plan is essential in the event of sensor failure, a situation the team encountered in the previous year of this competition. In the case of total sensor failure the robot enters a routine in which it attempts to maximize grass cut coverage by picking a random unmeasured heading angle and moving forward for a short amount of time and then choosing a new random heading. This option is a worst case scenario, but as the team has experienced, the worst case can indeed occur. Since the wheel encoder system is fairly strong the possibility of them failing is low; the motor controller will possibly fail before the encoders. Because of this the primary backup plan is to take the encoder data at face value an try to rely on the Kalman filtering without any sensor fusion with data from the other sensors. An active autonomous failure recovery has not be implemented on the AGM.

7 Obstacle Avoidance

Figure 4: Maxbotix Sonic Range Finder

The top level design for the obstacle avoidance routine consists of a system fed by two sensors. These sensors include ultrasonic range units and a digital video camera. The ultrasonic range sensors, as seen in figure 4, are positioned in such a way that there is one facing the front of the robot to aid in the avoidance of a head-on collision, two sensors are placed at the sides near the middle of the robot at 90 to the front of the robot to aid in avoiding turning into an object, and there are two positioned at the front 45 either way of the head-on sensor to aid in head-on and turning avoidance of obstacles. The ultrasonic range sensors have a range of up to 25 feet, providing the lawnmower with ample time to change course and steer clear of any objects which would be perceived as obstacles.

The web-cam is positioned above and at the front of the lawnmower providing a downward facing view of the direction of travel when the lawnmower is traveling forward. The web-cam serves a robust purpose of not only avoiding obstacles, but detecting the field lines which will be treated as obstacles in order to remain within the boundaries. Initially,as shown in figure 5, the vision program creates 9 possible paths the robot can take. The path of the robot is stored as a binary image, with 1 meaning a pixel is in the path, and zero meaning the pixel is not in the path. The set of possible paths are shown in the figure below.

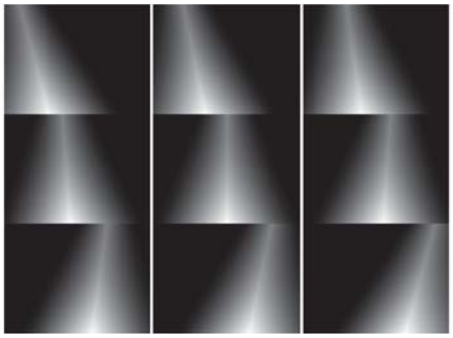

Figure 5: The set of possible paths that is used to determine the best path for AGM. Each mask is overlaid with the current classified image and each pixel is multiplied by the mask. Since the mask is binary as is the classified image; only obstacles in the path remain. From this all of the paths are compared and the one with the least amount of obstacle in the path is chosen.

7.1 Vision Algorithm

The vision loop consists of the following:

1. Take an image using the web-cam
2. From the image, learn the characteristics of grass
3. In the image, identify regions that are grass and those that are not grass
4. Points not identified as grass are classified obstacles
5. Using the masks generated as part of initialization, the amount of clutter in each path is computed and the robot controller steers the robot in the least cluttered path.

The key to the algorithm is the learning program. In each frame a small patch directly in front of the robot is sampled and as long as the robot is reasonably inside the boundaries, most of the patch would be grass. From this patch, a statistical model for the color of grass is determined. The assumed model is a Gaussian distribution. Based on this model, each pixel in the image is tested to see if it is grass (null hypothesis) or not grass (alternate hypothesis). This is a standard hypothesis testing program. Since, we use the color image, the underlying random variable is multivariate and one standard test is the Chi-squared test (also commonly known as the Mahalonobis distance measure).

7.2 Classified Image Description

A typical input image and the result of pixel classification are shown below in figure 6. Superimposed on the input image is the patch (yellow box) used to learn the statistical distribution of grass.

Figure 6: Original image on the left and the classified image on the right. The yellow box in the original image identifies the patch use to learn the foreground (grass).

8 Mechanical System

In this section all of the mechanical subsystems will be discussed. These subsystems include chassis design, mower/cutting deck, drive train, and electrical circuits. Each system had to operate safely and reliably, as well as fit into the overall design of the chassis. In designing each subsystem, many problems were encountered. These problems will be described in each respective section.

8.1 Chassis Design

The Robot is a four wheeled design that has two drive motors in the rear which utilize differential steering. This year, the entire robot was designed from the ground up. Primary goals for the new design were for it to be simple, robust, and low cost. The entire chassis was custom built with these thoughts in mind. When determining chassis material, aluminum modular tubing proved to be too expensive. Because of its cost and strength, various sizes of tubular steel were used to create the chassis.

Figure 7: AGM before electronics tray was installed.

The chassis was essentially built around the mower deck, but has the option to remove the deck and be used for other applications. This allows this vehicle to be used as a generic robotic platform for future generations of students who engage in the Intelligent System Club at the University of Michigan - Dearborn. In order to accommodate all of the various electronics, numerous areas were added to the chassis to house these electronics. All these areas which house the electronics are either mounted on drawer slides or easily removable. This allows any team member easy access to the lawnmower deck or battery compartment, which will allow for quick repairs or changes during the competition.

Figure 8: AGM after electronics tray was installed.

8.2 Dimensions and Mass

Feature	Dimensions/Mass
Chassis Width	0.763m
Chassis Length	1.17m
Chassis Height	1.01m
Motor Controller Platform	0.387m x 0.248m
dGPS Platform	0.284m x 0.64m
Wheelbase	0.66m
Mower Deck Width	0.5m
Battery Weight	19.7kg
Overall Weight	98kg (215lbs)

8.3 Mower Deck

For the mower deck, it was decided to purchase a commercially manufactured lawnmower. This not only saved money, but more importantly, time. Another big factor in the decision was the lack of resources needed to design and build a custom cutting deck in house. The lawnmower that was eventually purchased was a Homelite 20 inch cordless walk behind mower. This mower is powered by a removable 24V battery, which is the same voltage as the main battery supply for the rest of the robot. The battery's capacity is dependent on various factors including grass length, etc. The capacity should be sufficient enough for the needs of this project.

It became apparent that for this robot to be as flexible as possible, the mower deck had

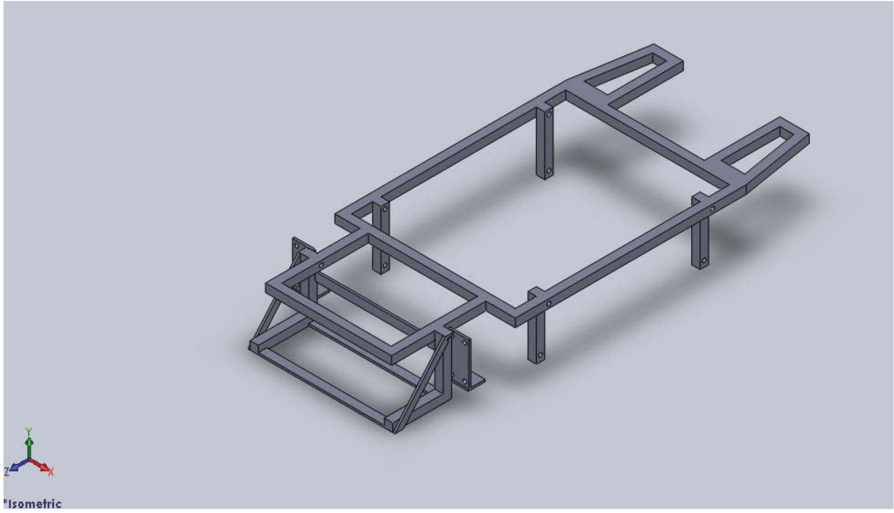

Figure 9: The Autonomous Grass Muncher Chassis

to have height adjustment feature. This allows to robot to be able to mow a large variety of terrains and grass lengths. Instead of designing and building the height adjustment hardware from scratch, the existing hardware that came with the lawnmower was altered in such a way for it to function with the new robot chassis. In the short term, this decision saved a lot of time on chassis construction. The deck suspension can be seen in the side view model of the chassis in figure 10.

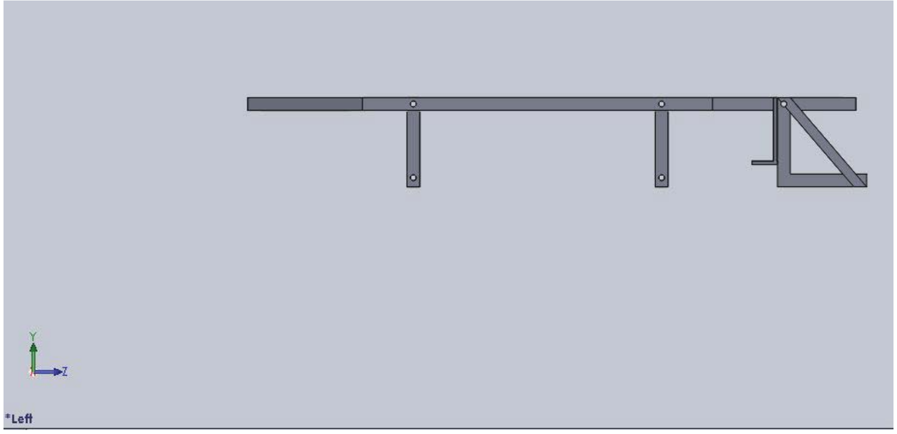

Figure 10: This is the CAD model of the chassis with the perspective focused on the left side of the vehicle. The battery compartment is in the back and the two post hanging down are where the lawnmower deck is mounted.

8.4 Drive Train

As with most of the robots that are built by the Intelligent Systems Club, this robot is powered by two Invacare wheelchair motors. These motors are incredibly diverse; they perform a wide variety of applications really well. They also provide a lot of torque, which is necessary for moving the weight of the robot over off-road terrain.

Since this robot is designed to primarily mow grass, new wheels were needed to aid traction in grassy environments. Most of the robots made by this club use standard wheelchair wheels, which are very narrow. These narrow wheels do not fare well on surfaces other than pavement, so new wider off-road wheels were purchased. The new wheels greatly improved traction on grass, and should allow the lawnmower robot to maneuver on grassy terrain without any major issues.

Figure 11: The Autonomous Grass Muncher Chassis

8.5 Power

The main power source is comprised of two Optima yellow top batteries, which are wired in series to create a 24V DC power supply capable of providing 55Ah of power. These deep cycle batteries were chosen because they have a long life, are spill proof, more vibration resistant than a standard lead acid battery, and recharge faster than a standard battery. Running the motors at a high speed, these batteries provide 1.5 hours of run time.

The lawnmower deck is powered by its own factory battery, and from initially testing this spring, it has an average run time of between 35-50 minutes depending on grass conditions. This batteries capacity will be sufficient for completing the course on one charge. In addition to the lawnmower being powered on its own, the on board laptop that will perform all the necessary computations will also be powered by its own battery. The laptop will also have a backup 12V DC battery powering an AC inverter, which allows for the laptop to be plugged in and keep a charge during the competition. All of the remaining electronics are powered from 24V and 12V DC power buses ran from the Optima batteries. All connections from the battery are ran through fuses first, to provide safe connections for the various electronics which are inboard.

9 Safety System

Safety is a great concern when dealing with any level of autonomy, especially when the autonomous vehicle is of potentially dangerous nature like a lawnmower. There are several layers of safety incorporated within the Autonomous Grass Muncher. Three emergency options exist to force the robot to cease moving as well as cease the cutting function. There is a physical emergency stop button at the rear of the robot which when pressed down will create an open circuit and cut all power to the driver motors as well as the blade motor on the lawnmower. There is also a wireless emergency stop which is a remote starter unit for a vehicle which when activated produces the exact same results as the physical E-Stop. When either is activated, the physical plunger must be depressed (if physically activated, this has already be done) and then pulled out back to it's standard position in order to complete the circuit and allow the power to be restored. A third stopping option is to press a button on a wireless remote which forces the software to quit and exit. Due to the fact that software can at times enter an endless loop and become non-responsive, the physical and wireless emergency stops are a more reliable and safe option than the software exit is, but the software exit has proven to be useful when testing and has therefore not been removed.

10 Cost Summary

Component	Retail Value	Amount Spent
Homelite 20" Electric Lawnmower	\$300.0	\$100.0
Chassis	\$200.0	\$200.0
Invacare Wheelchair Motors	\$1000.0	\$0.0
RoboteQ AX2850	\$645	\$645
VectorNav VN100 IMU	\$800	\$0
Hemisphere ***GPS	\$5800.0	\$0.0
Turck T8.3720.5411.0200 Wheel Encoders	\$276	\$0
MaxBotix XL 1320AE Ultrasonic Sensors	\$150	\$0
Microsoft LifeCam	\$50	\$50
Acer AspireOne Netbook	\$200.0	\$200.0
Physical E-Stop	\$50.0	\$50.0
Wireless E-Stop	\$50.0	\$50.0
Miscellaneous	\$200.0	\$200.0
Total	\$9721.0	\$1495.0

11 Conclusion

The Intelligent Systems Club at the University of Michigan - Dearborn is competing in the Autonomous Lawnmower Competition for the second time. Last year, with the robot named GOAT, UM-Dearborn took 6th place. This was satisfying because the team only began development on the project a month before the competition. The goal this year is to place better than last year and there is no reason why this should not happen. AGM is far better platform than GOAT and the software development has matured since last year into a full fledged system tightly coupled with the drive controller and the external sensors. Last year, the team did all development using toolboxes in MATLAB. This was very inefficient and resource consuming. Two during last years competition the computer running MATLAB crashed at very inopportune times; prompting a restart and loosing points for the team. A much more stable system is now in use. Leveraging the efficiency of the C programming language and it's compilers and also the stability of the Ubuntu Linux operating system, AGM will not suffer the same computer issues that GOAT suffered last year.

The navigation system developed for the Autonomous Grass Muncher is comprised of three navigational aids and two obstacle detection methods. Primary focus has been on the wheel encoder interface developed by Tuo Xiang as part of a senior design project. The interface to the GPS and the IMU are still premature but are part of another senior design project in development by Kris Bechamp, Michael Pearson, Mel Malabanan, and Mark Lawrence. These two interfaces are to be implemented as augmentation resources to correct the data provided by the wheel encoders. In case of errors from slipping, it is hoped that the GPS and IMU data is sufficiently accurate enough to complement the encoders but will bot be relied on heavily because their update rates are far slower than the encoders.

The control system has been determined to be stable by analysis of it's poles. This is under the assumption that this is system, the way it is now, is to be used in it's intended fashion in a waypoint navigation scheme. Under other conditions the control system's stability is not known. Along with the guidance method that the team is attempting to accomplish and with a reliable sensor fusion and filtering process it is the team goal to have developed a fairly robust autonomous lawnmower solution. In the future, such a design can be packaged with a convenient user interface with the intent of simplifying the mapping process to be applied to any general area. This would allow the lawnmower to be used residential.

The team has put much effort into this vehicle and is looking to improve upon the previous years performance. Since, the last competition many aspects of design have been learned, include control analysis and sensor filtering. The robot platform is completely new and has been built to serve the Intelligent Systems Club for many years as a robust and configurable robotic platform. Thanks to this competition, it's organizers, and sponsors, the student of the University of Michigan - Dearborn have had the opportunity to expanded the knowledge in the art and science of navigation, robotics, systems integration, physical modeling, and software design.

12 References

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2 2011 Autonomous Lawnmower Competition - Rulebook. rules2011.pdf