An Autonomous Lawnmower 'The ManScaper'

Andrew Cochrum, Joseph Corteo, Jason Oppel, and Matthew Seth

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — This paper presents a design for an autonomous lawnmower. The design builds upon a commercial electric lawnmower and adds features to make the process autonomous. The lawnmower uses sensors to avoid obstacles. Computer vision is used to define the mowing boundaries and reference the lawnmower position during use. The microcontroller stores and manipulates the positional data to determine the path of the mower. The ManScaper autonomous lawnmower is a useful device to improve the lawn mowing experience with little user interaction.**

***Index Terms* — Automation, Navigation, Computer Vision, Ultrasonic Sensors, Motor Controllers, Microcontrollers.**

I. Introduction

The ManScaper is an autonomous lawn mower that will take care of all of a user's grass cutting needs with very little contact from the end operator. By handling this task autonomously, the user is free to relax and be worry free about their lawn. This project improves upon existing designs using advanced technologies to efficiently perform its dedicated task. To accomplish this task, the ManScaper has a specific set of goals which are to be easy to use, accurate, and efficient.

The ManScaper was designed using a commercially available cordless electric mower. The existing lawnmower battery and blade motor system was used to handle the grass cutting function. By choosing a working product for the foundation, design time and work was saved for the autonomous features.

This project uses a variety of features to undertake its job. The primary duty necessary for automation is to track the location of the mower as well as its environment. Tracking and mapping are performed using a combination of computer vision and an integrated dead reckoning system using onboard sensors. An outside high-mounted camera views the area, which is interpreted using computer vision. This method allows a precise location of the lawnmower to be determined at any given time. In addition, the computer vision function maps the lawn while marking the boundaries. Onboard sensors are continuously read and evaluated to keep a relative location. The combination of all of this data provides the precise measurements required to navigate the lawnmower. In addition to location mapping, an obstacle avoidance system will be integrated into the project. Using ultrasonic proximity sensors, the autonomous lawnmower can easily detect obstacles preventing any number of unfortunate mishaps.

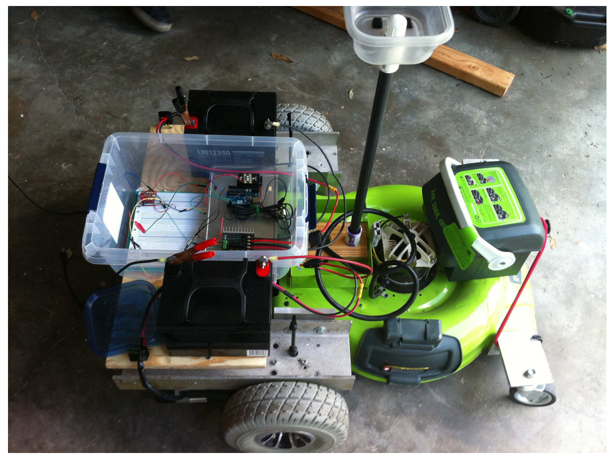


Figure 1 - ManScaper lawn mower design prototype

The data collected from the navigation and obstacle avoidance systems is evaluated by an embedded microcontroller. Using encoded path algorithms, an efficient route for mowing the lawn while avoiding obstructions is mapped. A feedback loop design is used to continuously monitor and adjust this path. This data is fed to the drive system of the lawnmower through the drive motor controller. The data passed to the motor controller enables forward and reverse motion, braking, and steering used to maneuver the autonomous lawnmower. The power system of the project is designed to allow the lawnmower to execute long enough to complete its function.

The primary motivation for this project is to remove the chore of mowing your lawn. By creating a lawn mower that handles this task autonomously, the user is freed from this physically demanding and time consuming task. The projected design helps those with physical limitations who could not otherwise mow their own lawn. Even without a physical limitation, the autonomous lawn mower provides the user with more free time. This freedom is provided in a worry-free platform in which little user interaction is required. The project idea was introduced by group member Andrew Cochrum. His initial design idea was to create a fully autonomous lawn mower that maps the target yard and lawn mower locations using triangulation methods from

RF receivers/transmitters. The design is similar to the previous senior design project called iMow. It is also an improvement on existing consumer autonomous lawn mowers including the John Deere Tango E5. The available commercial autonomous lawnmowers only cut in a random pattern. By implementing an embedded path/route algorithm, the ManScaper can mow the lawn much more efficiently than the commercial products. A variety of location methods were researched to determine the most effective method for the project.

With no outside funding or sponsorship provided, the final design of the project was built in a manner to keep the overall cost of the project as low as possible. The project was designed with the ability to add on additional features after the initial prototyping phase.

II. System Overview

In keeping with the motivation behind the project, the goal of this project is to reduce end-user work through the utilization of an easy-to-use device. The ManScaper is designed to learn your yard in one initial setup period. This project improves on existing consumer products by removing the need to bury insulated wires to identify the boundaries of the lawn. This complies with the stated motivation to reduce work by eliminating this tedious, initial setup.

A specific set of standards were set for our design. These design specifications determined our design functions and the parts to be used. The overall project specifications to be met through our design are as follows:

- Mower size: 26” x 35” x 12.5” (W x L x H)
- Mower location accuracy: Accurate to within 12”
- Forward speed: approx 1 mph
- Obstacle detection distance: 2 cm to 3 m
- Average lawn size: 0.25 acre
- Time to cut test area: ≤ 30 minutes
- Battery life: ≥ 1 hour

These design specifications were used to determine the design decisions throughout the entire process.

The overall system design consists of four sections in direct communication with each other. These sections consist of 1) location mapping, 2) drive and orientation, 3) obstacle avoidance, and 4) path calculation. Each of these subsystems consists of sensors and parts which communicate through a central microprocessor. The location subsystem also needs to communicate wirelessly with a camera mounted outside of the cutting area connected to a laptop. These subsystems work together to create the autonomous system. The overall block diagram showing the interaction between the components is shown in Figure 2.

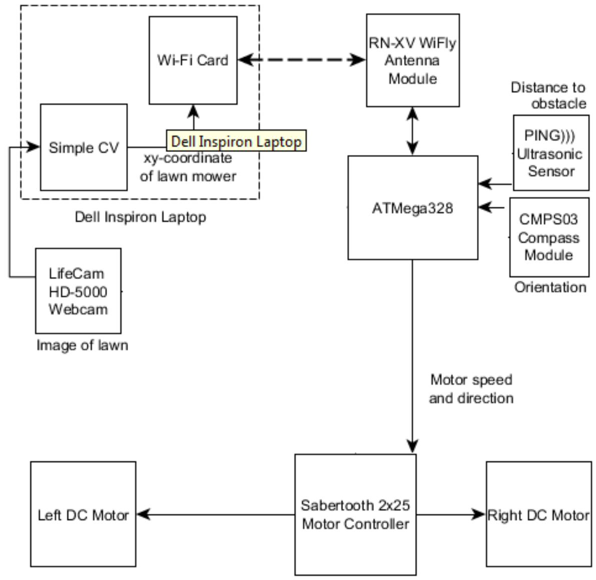


Figure 2 - Overall Block Diagram

A. *Location Mapping*

Location mapping is necessary for automation of the lawn mower. Using a camera mounted outside of the mower, a computer vision program is used to track the current location of the lawnmower as well as to map the entire cutting area. Location tracking is done continuously throughout the use of the mower. The mapping is handled during an initial setup phase.

The initial setup phase consists marking the boundaries of the cutting area and saving the two-dimensional coordinates in its internal memory. The boundaries will be setup using easy to place markers. A user friendly setup is provided to demarcate the boundaries of the area to be mowed. Using a computer vision process, the location of the lawnmower can be maintained and the autonomous vehicle can stay within its boundaries. For prototyping, a standard laptop will be used to run the computer vision program with information from the camera to simplify the overall design. By matching its location to the yard location determined from the learning mode, this lawn mower design will give the same accurate cut each and every time. This is a great improvement in efficiency over available consumer devices which cut in a random pattern until the entire area has been covered.

B. *Drive and Orientation*

The ManScaper is driven by a pair of motors and wheels from an existing electric wheelchair. The motors provide enough power to move the lawnmower across the typical yard terrain. Communication to the drive motors from the microcontroller is handled with a motor controller. The motor controller converts data sent from the microcontroller to commands to turn the wheels forward, reverse, or to stop them.

To make sure that the mower is travelling along the correct path, the ManScaper will need to remain correctly oriented. Proper positioning is maintained through the use of the camera and computer vision system. Orientation will be evaluated with the use of an onboard digital compass, or magnetometer. The data gathered from the digital compass is used to maintain a proper course and for turning in the correct direction.

C. Obstacle Avoidance

Safety is an important factor that was considered for the ManScaper. Implementation of obstacle avoidance is the primary subsystem used for the safety of the project vehicle. Through the use of an ultrasonic sensor, the mower discerns the location of obstacles present within the cutting area delimited by the border established during the mapping phase. Once an object is detected in its current path of motion, the mower change its directional orientation until the object is no longer in its “field of view,” and proceeds around the obstruction. To further increase safety, an easily accessible kill switch is mounted on the mower itself.

D. Path Calculation

In addition to ease of use through automation, the goal of this project was to create an autonomous lawnmower that is both accurate and efficient. A majority of current, commercial products sweep the area enclosed by the buried perimeter wire in a random fashion. Once the mower reaches the perimeter of the yard, it rotates at a set angle and proceeds in a straight path until it encounters a boundary location once more, at which point the process repeats itself. It is apparent that such a method could become quite inefficient due to a variety of factors. For instance, unnecessary redundancy would most likely occur in which the mower continually passes over a previously cut section of the lawn. To eliminate this problem, the mower keeps track of its previous positions during the current cutting session, and attempts to maneuver around these areas.

III. Lawnmower Design

To simplify the overall design of the project, an existing market available lawnmower was used for the main chassis of the mower and cutting platform. To conform to our design requirements, the platform needed to be electric with a removable rechargeable battery. The initial design called for the power system to control both the blade and the rest of the designed system with the same battery. However, noise concerns resulted in keeping the battery to power the blades separate from the rest of the project. The lawnmower chassis chosen for this project was the GreenWorks 25222 20” 24V Cordless 3 in 1 Mower. This lawnmower had a highly recommended battery life and the metal frame was adequate for the additional fabrication requirements. The mower blade is turned on and off by a simple 25 amp relay via the microcontroller.

To drive the ManScaper, a set of drive motors and wheels needed to be added to the existing chassis. These new driven wheels were added to the back of the mower and the existing front wheels were replaced with a pair of freely rotating casters. Since the electric motors were loaned to us by the UCF Robotics Club, motor selection was simple. The loaned motors provide more than enough power for our application. The motors are powered with a 24V supply and, during typical execution, draw about 1A in full forward mode.

Both motors were mounted onto an extension of the main chassis with custom brackets. The motors drive the wheels directly. Since the motors are already geared, no additional gear reduction for power was necessary. Each motor was equipped with a manual clutch integrated into the motor itself. This allows the motor can be disengaged from the wheel. When the clutch is disengaged the wheels spin freely with no interaction from the drive motors. Having the ability to disengage the clutch was useful not only for testing, but also for pushing the mower into place when not in autonomous mode.

Although many methods exist for controlling 24VDC motors, the two most simplistic ways for controlling a motor are through the use of an H-bridge or by using a manufactured motor controller. The first method for controlling DC motors is through the use of an H-bridge. This is the cheapest way to control a DC motor since a set of high current switches may only cost about $50, but it has its disadvantages. The disadvantage of using an H-bridge is that the amount of current that flows through the switches is all or none. This means that the motor is full on when the switches are enabled. This makes for less precise control of the DC motor’s speed and can be problematic if the motor runs at too high a RPM for the desired application when powered on. The second method for controlling DC motors is through a motor controller. This is the more expensive way to control DC motors as most high current motor controllers start at about $100 and go up from there. However, the use of a motor controller allows for more precise control of the current that is supplied to the motors which translates to accurate speed control. Using a motor controller is ideal for use with automated vehicles since the vehicle does not operate at high speeds and the vehicle needs to stop for objects and smoothly start up again. If the automated vehicle can slowly speed up from a stopped position, then the sensors and digital compass will be able to function more accurately and keep the vehicle on a preset track. For these reasons a motor controller is worth the extra cost in building an automated vehicle to ensure navigational accuracy.

After looking at various manufacturers, the most highly rated and widely used motor controller was the Sabertooth 2x25 motor controller. According to the specifications for the Sabertooth motor controller, it can supply two DC brushed motors with up to 25 amps of continuous current each with a peak current of 50 amps to each motor. The Sabertooth 2x25 also accepts various control inputs such as analog voltage, radio control, serial, and packetized serial. The mower turns and navigates via differential steering achieved by using each motor independently as well as free castering wheels on the front of the chassis. Independent control of speed and direction of each motor make the controller ideal for differential drive applications. Being a regenerative motor driver means that the batteries get recharged when the controller receives a command to slow down or reverse a motor. This will help with extending the battery life so that as much of the target area as possible gets mowed on a single charge. The Sabertooth 2x25 is able to handle control of both motors. The Sabertooth has built in overcurrent and thermal protection.

With the feature set on the Sabertooth 2x25 motor controller there are five different methods used to control the motors. The first is analog control: a 0V to 5V analog input is connected to terminals S1 and S2. 0V is full reverse, 5V is full forward, and 2.5V is stop. The second method for controlling the motors is through an R/C input mode. This allows the motor controller to be used with a standard hobby radio control transmitter and receiver. The third method for controlling the motor controller is through microcontroller pulses connected to terminals S1 and S2. A 1000us – 2000us pulse controls speed and direction, 1500us is stop. The fourth method for controlling the motor controller is through simplified serial commands. Serial data is sent to input S1, sending a value of 1-127 will command motor 1. Sending a value of 128-255 will command motor 2. Sending a value of 0 will shut down both motors. The last method for controlling the motor controller is through packetized serial commands. Packetized serial uses TTL level serial commands to set the motor speed and direction. Packetized serial is only a single direction interface. The transmit line from the microcontroller is connected to S1. The microcontroller's receive line is not connected to the Sabertooth 2x25. Because of this, more than one Sabertooth 2x25 can be connected to the same serial transmitter. This is because packetized serial uses an address byte to select the target device. This large variety of control methods makes the Sabertooth 2x25 motor controller easy to integrate into any automated vehicle design and allows for simple programming to control the differential drive motors of the vehicle.

Serial data from the microcontroller is used in the ManScaper to independently control each motor. The serial data is passed as one byte with a value from 0 to 255. A value of 0 stops both motors. Values of 1 to 127 control one motor with 1-63 being variable speed reverse, 65-127 as variable speed forward, and 64 as a stop command. Likewise, the second motor is controlled with the values from 128 to 255. In our application the drive motors will lead the lawnmower along its path pulling the castering wheels. Pulling the casters rather than pushing them helps to better maintain the drive path.

The ManScaper power subsystem design is broken into two main subsections: the battery required to run the project and the voltage regulation circuit required to supply the required power needed by each electronic device. Since this project is a prototype with budget limitations, a lead acid battery is the most feasible options to supply power to the device. The slow charge time of lead acid batteries is not a hindrance to the function of this project. Choosing a battery that allows the lawnmower to fully cut the entire lawn ensures that the lawnmower will not need to be ready again for a time period of almost a week. This allows plenty of time for the battery to charge. Multiple batteries will be used in the final design due to the high power requirements each by the drive motors. 24V is necessary to power the motors and two 12V batteries in series provide the voltage needed. The factory supplied battery will be used for the cutting mower and the additional batteries for the rest of the system. The power for the remaining electronics is supplied using the added batteries. The electronics on the mower use less than 1A and each motor draws about 1A each. Two 33Ah batteries were chosen to give the lawnmower more than enough power for the lawnmower to run for approximately 30 minutes. Note that smaller batteries could have been used, but these were chosen as the current draw of the lent motors was unknown at the time of their purchase.

Voltage regulation is required to provide steady 3.3 to 5 volts of output from the 24 volt batteries. Due to the large difference in input and output voltages, a switching regulator was advisable for the voltage regulation needs for the project. A buck converter that can handle 24 volt input and provide about 1 amp output was required for this project's voltage regulation needs. The LM2825 buck converter can handle an input voltage range from up to 40 volts and can source up to 1 A. Texas Instruments provides a fixed output

LM2825 that gives a fixed 5 volt (or fixed 3.3 volt) output voltage. The fixed output LM2825 switching regulator is a fully function IC with no additional electrical components needed for implementation. Using the fixed voltage part simplifies the overall design of the voltage regulator circuit and lowers the part requirement on the final printed circuit board design.

IV. Obstacle Avoidance

The obstacle avoidance subsystem for this project takes inputs from onboard sensors which are then interpreted by the microcontroller. The primary sensor used in the obstacle avoidance subsystem is an ultrasonic proximity sensor. The information gathered from the ultrasonic sensor provides the data required for the lawnmower to avoid any hazards while performing its mowing functions.

A proximity sensor is used for obstacle detection and avoidance. For this project, an ultrasonic sensor is used to detect impeding objects along the mower's current path. This sensor is mounted onto the front of the lawnmower so that it can detect the obstacles while the mower is moving forward. To accommodate an appropriate stopping and turning distance, the ultrasonic sensor needed to be able to detect objects directly in front of the lawnmower (0.0 inches) up to a distance of about 18-24 inches. In addition, the sensor had to be able to detect objects with a width of approximately 2 inches or greater.

For this project, the Parallax PING))) ultrasonic sensor was determined to be the best tested for the obstacle avoidance subsystem. This sensor is desirable due to a variety of factors. It has a wide input voltage range, low current draw, a considerable amount of user control, and a price in line with other sensors of its type. There was also a considerable amount of information available to be modified for our application. Under typical applications, the PING))) sensor was able to detect objects in a 40 degree range as shown in Figure 3.

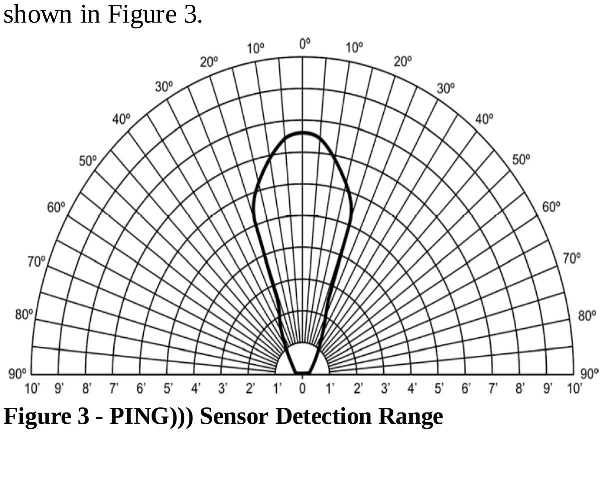


Figure 3 - PING))) Sensor Detection Range

The software application for this subsystem reads all of the data from the above mentioned sensors. Using this information, it is determined if an obstacle is detected. Once an obstacle is detected, the software stops the mower and calls an obstacle avoidance routine. This routine marks the object location off in the internal map as an obstacle to avoid and recalculates a new route using the embedded path calculation algorithm. This area is then avoided in any future passes to avoid running into or over the detected object.

V. Computer Vision

Several options were evaluated for computing the absolute position of the autonomous lawn mower. Initially, ultrasonic beacons were to be placed along the perimeter of the lawn and trilateration would be used to determine the xy-coordinates of the lawn mower within the confines of the area enclosed by the beacons. Unfortunately, the accuracy of this system quickly deteriorated as the lawn mower approached the boundaries of the lawn, a problem that could be rectified by the addition of more beacons. However, since these beacons would each require a separate custom PCB (printed circuit board), an ultrasonic transmitter and an independent power system, the cost of development was quickly driven to an unacceptable price (especially since this project is not sponsored, and thus will be funded completely by its members). Also, the time required to troubleshoot and successfully implement such a system would consume much of the fabrication and testing period, leaving little time to employ the other features.

After passing on RF location methods, computer vision methods of tracking were researched. By using landmark navigation through computer vision, most of the development cycle was be centered around software development, which allows for low cost, fast prototyping cycles and flexibility in terms of feature sets. When written correctly, the computer vision software produces accurate results at a fraction of the cost necessary for implementing one of the previously mentioned techniques.

Several options are available for computer vision software. MATLAB offers a "Computer Vision Toolbox" that includes a suite of image processing algorithms and various functions that interface with input and output devices. However, the MATLAB license is expensive, and the program itself requires a large install and consumes a lot of system resources on the host PC. SimpleCV is an open source framework for building computer vision applications using the Python programming language. It is built open the OpenCV library that, apart from being open-source, was created specifically for users that require the power of MATLAB at no additional cost. SimpleCV is dependant upon several Python packages such as NumPy (used for matrix manipulation), SciPy (includes a multitude of functions necessary for executing complex mathematic operations such as integration) and matplotlib (used for generating various plots), all of which are open-source and completely free.

Another added bonus of open-source software is the robust user base, which serves as an invaluable supply of pre-written code that can be implemented and modified without any form of legal recourse. This helped to further shorten the time of development since computer vision is a relatively mature technology and thus many of the problems associated with it can be solved by finding the appropriate function and implementing it within the framework of an existing program.

The input to the SimpleCV program will be the live video feed from the LifeCam HD-5000 Webcam manufactured by Microsoft, which is connected to the host laptop via a USB cable. Since the SimpleCV program will be running on a laptop (separate from the lawn mower chassis) the computation of the xy-coordinates of the lawn mower will not impact the performance of the microcontroller. The microcontroller simply receives the coordinates wirelessly via the connected onboard receiver and uses them in conjunction with the outputs from the magnetic compass module and the ultrasonic distance sensor. Figure 4 illustrates the support structure that will be used to elevate the webcam above the ground so that it can completely survey the lawn and the lawn mower navigating through it.

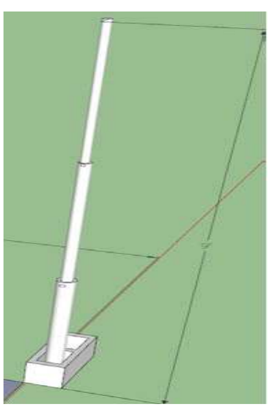


Figure 4 - Webcam Support Structure

Figure 5 shows how the webcam support structure will be placed in relation to the lawn. The beige cylinders along the perimeter represent brightly colored plastic cones that will be used by the SimpleCV computer vision program to establish the boundaries of the lawn. Using various image processing techniques and algorithms available within the SimpleCV library (e.g. blob detection, object detection, shape detection etc.), a coordinate system will be created in software to assist in the calculations of the absolute location of the lawn mower, throughout its navigation of the lawn.

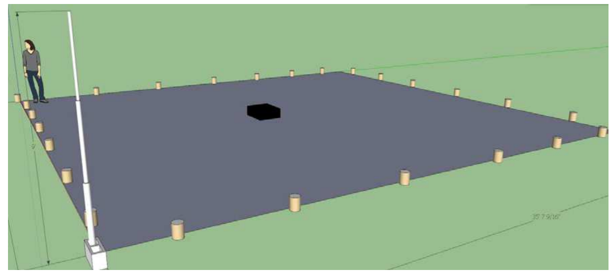


Figure 5 - Overall Boundary Setup With Computer Vision

Figure 6 shows an example of how the computer vision program will be able to calculate the distance to the lawn mower (black box) and from this, infer the absolute location of the lawn mower within the yard. Using blob detection, the SimpleCV software will compare the size of the blob created by the lawn mower through each frame of the live feed. If the blob is becoming smaller and is moving across the screen in the vertical direction, it can deduce that the lawn mower is moving away from the camera, in the direction of the camera’s field of vision. Using this information and comparing this to the data from the encoders, an absolute position can be determined.

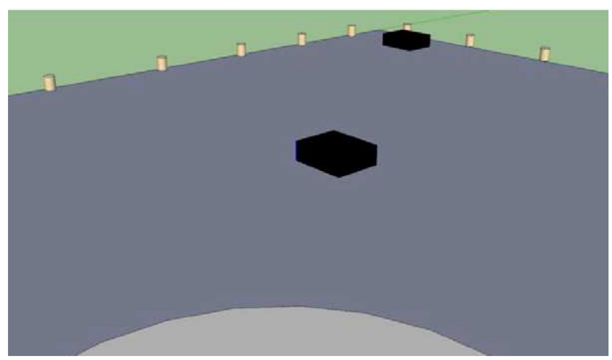


Figure 6 - FOV From The Webcam On Structure

Communication between the computer vision system and the microcontroller on the lawnmower is controlled using a standard Wi-Fi setup. The RN-XV wireless antenna was chosen over its competitors for its low current consumption when receiving data (the lawn mower will be continuously receiving the xy-coordinates from the laptop located at the base station, rarely needing to send any data back to it), and its low cost. A telnet connection is established through a dedicated router allowing the onboard RN-XV wireless component to be on the same network as the laptop running the computer vision software. Using the telnet connection, bytes of location data and mower control data can be sent to the lawnmower during its execution.

VI. PATH CALCULATION

The path calculation subsystem of the ManScaper is the brains of the design. The path calculation takes the inputs from the camera and onboard sensors and compares the information with the mapped area stored in the microcontroller's memory. Path calculation is broken into two subsections: 1) location detection and 2) path algorithms.

Location detection starts with the map of the area stored in the microcontroller's memory. For the ManScaper, the area map will be stored in the onboard EEPROM on the ATMega328P. The ATMega328P has 23 I/O pins providing more than enough for our application. For memory, the ATMega328P has 32KB of ISP flash memory to store the program data and 1KB of EEPROM for mapping data. It also includes 2KB of SRAM for variable storage during program execution.

For area mapping, the area to be mowed is divided into an array of nodes. To maximize the overall cutting area, each node will be measured as a 20"x20" square. With a 20" mower blade, a node of this size will be covered by the cutting area so that it can be marked off as cut when passed over. An example of a pre-mapped grid area is shown in Figure 7.

For this application, each node will be mapped using only two status bits. The first status bit contains data for whether or not the area is an obstacle with a 1 being a node to avoid. Any nodes within the cutting boundaries are marked with a status bit of a 0 so that it will be passed over during mowing. The second status bit stores information on whether or not the node has been mowed. For this bit, all areas to be mowed are initialized with zeros. As the mower passes over the node, the path software marks the area as cut by changing this status bit to a 1. Any mowed areas will be attempted to be avoided, but are allowable to be passed over again as they do not contain an obstacle.

With two status bits per node, the EEPROM storage area can hold a node area of 64x64 nodes. With a node size of 20"x20", the total map-able area using this setup is 0.26 acres. This meets our 0.25 acre minimum is our project design specifications. A larger area could be mapped using additional memory card storage. For testing purposes, areas much smaller than 0.25 acre were used. Since the principles of mapping and obstacle avoidance are scalable, a small area is sufficient for prototyping. In cases of areas smaller than the maximum map-able area, the nodes outside the boundaries are marked so that the obstacle status bit is a 1. This marks that node off as one to avoid, thus not affecting the lawnmower's performance in cutting the test area.

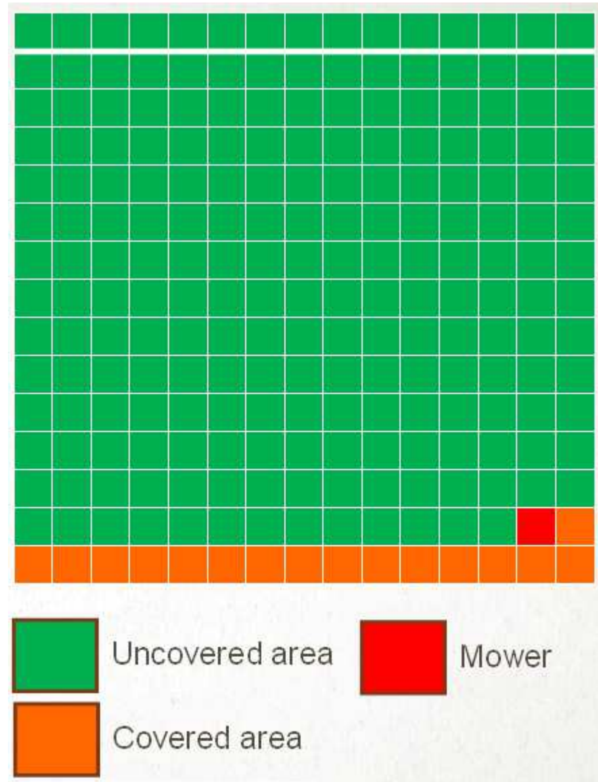


Figure 7 - Mapped Grid Area Example

Once the area is mapped, the lawnmower needs to pass through each node in the stored array. The maintenance of the continuation of the path is handled through a combination of an onboard dead reckoning system and location data from the computer vision subsystem. Dead reckoning tracks the lawnmower's location relative to the last verified location. The dead reckoning location is calculated using the speed of the drive wheels in conjunction with data from the onboard digital compass. Additional accuracy could be obtained using shaft wheel encoders installed on the drive motors to measure the wheel turns. However, encoders were unable to be obtained in time to be used for this project design. Due to the fact that the drive motors were loaned and that no data was found on the motors, appropriate encoders were unable to be secured. Given further time and funding, encoders could be added to the design which should improve the dead reckoning accuracy.

For the ManScaper, the HMC5883L triple axis magnetometer was selected for orientation. This compass module was chosen over its more advanced counterpart (CMPS10) since the latter included a built-in 3-axis accelerometer to compensate for measuring the vertical component of the Earth's magnetic field when the module is not parallel to the ground. Normally this would be desired, however since this compass will be mounted on the lawn mower chassis, it will be subjected to high levels of vibration, causing the CMPS10 model to experience excessive noise (regardless of horizontal orientation).

The Honeywell 3-Axis HMC5883L digital compass claims an accuracy of 1 to 2 degrees. During testing, the compass had severe issues of accuracy cause very unstable results. This was corrected by adding offsets to each axis during a calibration phase. To properly calibrate the digital compass, an initial calibration is performed upon each startup. This calibration procedure slowly rotates the lawnmower a full 360 degree rotation during which the compass offset is calculated improving the accuracy of the compass to with 5 degrees of actual values. This degree of accuracy is fine for this application as only relative heading are needed for turning 90 or 180 degrees.

Using continuously measured input from the digital compass, the current heading of the lawnmower can easily be maintained. Should the lawnmower veer of its heading, one wheel can be slowed down or sped up to compensate and get back on the correct bearing. If the heading ever gets too far off, the mower is programmed to stop and re-orient itself back towards its correct path.

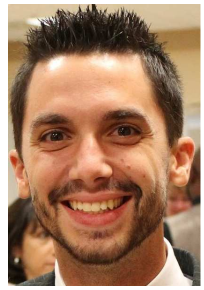
The path of the lawnmower is determined by finding the next node to be cut along the desired path. If the next node is an obstacle (hard coded or detected with the ultrasonic sensor), a new path need to be recalculated. The embedded path algorithm will initially try to find a path by traversing to an uncut node. The surrounding node status bits are checked to find uncut neighboring nodes. Should none of the surrounding nodes be uncut, the path algorithm tries to go around the obstacle to find a new path. In all cases, the path algorithm will never look to cross the predetermined area boundaries.

VII. Conclusion

The final design of the project was attempted in a manner to keep the final cost of the project as low as possible. The group members were fully responsible for the financial responsibilities of the project design due to an inability to secure outside funding or sponsors for the project. Efficient use of parts allowed us to maintain a reasonable budget and complete the design.

Work on the ManScaper has provided each of us with an invaluable learning experience. The design and prototyping during two semesters has allowed us to work through many issues and improve our overall troubleshooting skills. We also gained team building experience that should carry over into our careers.

Biography



Andrew Cochrum will be graduating from the University of Central Florida with a Bachelor's of Science in Electrical Engineering. Andrew has a background in computer and boat repair. Andrew plans on remaining in the Orlando area to pursue his career after graduation.

Joseph Corteo will be graduating from the University of Central Florida with a Bachelor's of Science in Electrical Engineering. Upon graduation, Joe plans on finding a job to start his career.

Jason Oppel will be graduating from the University of Central Florida with a Bachelor's of Science in Electrical Engineering. Upon graduation, Jason plans to start his career as an electrical engineer in the Orlando area. He is currently a member of Eta Kappa Nu – IEEE honor society.

Matthew Seth will be graduating from the University of Central Florida with a Bachelor's of Science in Computer Engineering. Matthew seeks a career in which he could effectively utilize and enhance his experience with embedded systems, programming and networking. He is currently involved in leadership and music at his church and hopes that his computer engineering experience can be a potential benefit to his church and life in the future.

References

[1] "PING))) Ultrasonic Distance Sensor (#28015)." 4 Feb. 2013. Parallax Inc. <http://www.parallax.com/Portals/0/Downloads/docs/prod/acc/28015-PING-Sensor-Product-Guide-v2.0.pdf>.