UNIVERSITY OF EVANSVILLE

UEzMOW 4.0 Technical Report

ION Robotic Lawnmower Competition 2011

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ACKNOWLEDGEMENTS

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I. INTRODUCTION

UEzMOW 4.0 is a senior capstone design project created with the intention of greatly reducing the amount of man-hours needed to mow one's lawn. The end result will be the creation of an autonomous lawnmower. The scope of the project ranges from utilizing a means of navigation for the robot to the actual cutting of the grass. Other tasks in between these include communication between peripherals, controlling robot movement, and developing algorithms for obstacle avoidance. This project was selected due to its potential to have a lasting positive impact for all of mankind. Our design will be entirely electric, eliminating the need for an internal combustion engine thus greatly reducing the carbon footprint of tomorrow's lawnmower. The robot will compete in the advanced autonomous portion of the 8th Annual ION Robotic Lawn Mower Competition in Beavercreek, Ohio, on June 2-4, 2011.

Many potential issues arise when considering the idea of building a robot to perform grass cutting duties. Typically, lawn mowing devices are large vehicles with a lot of mass. To make matters worse, typical push type lawnmower engines spin at a rate of 3,600 revolutions per minute (RPM) [1]. This makes a lawnmower potentially a very dangerous item. Because of this, great care must be taken to insure safe operation. Various safeguards and obstacle detection methods are utilized to avoid common items typically found in one's yard such as flowerbeds and pets.

II. PROBLEM DEFINITION

The requirements for this project are set forth by the Institute of Navigation (ION). The lawnmower must be able to mow a predetermined course. For the advanced autonomous contest, the course is an irregular L-shape. The lawnmower must also avoid various obstacles; both static and dynamic.

A. OBSTACLE DESCRIPTION

The dynamic obstacle is a remote controlled vehicle with a stuffed dog attached to the top. The vehicle will approach the front of the mower (± 90° of the velocity vector) at a random time during the mowing of the course. The obstacle will stop in front of the mower and remain stationary for 30 seconds. When encountered by the obstacle, the lawnmower must stop and wait for the dog to vacate the path of the mower. The dog is approximately 61 cm tall and its feet will be no more than 10 cm above the ground.

Two separate static obstacles are used in the advanced competition. First, a large flowerbed is placed in zone one. The flowerbed is not to exceed 5 m in any dimension and must be at least 2 m from any boundary of zone one. Along one side, a concave portion with minimum radius of 2 m is present. A 15 cm high black plastic edging borders the flowerbed. Finally, a white picket fence surrounds two sides of zone two. The fence is 36 inches high and each of the two sections is 8 feet long.

B. COURSE DESCRIPTION

The advanced autonomous course consists of three zones. A minimum of a 2 m safety buffer surrounds the course. Zone one is approximately a 10 m by 8 m rectangle, however, none of the sides in the zone is required to be square. Both the flowerbed and dynamic obstacle reside in zone one. Zone two is located at one of the corners of zone one. It is at minimum a 2.4 m by 2.4 m. Located around two of the sides is the picket fence obstacle. The grass adjacent to the picket fence, as well as the flowerbed, is considered zone three. Even though it is the smallest zone in the course, it is deemed the most difficult, thus is weighted more heavily. A complete list of contest rules and the formula used to determine the percentage of grass mowed can be found in Appendix I.

II. HARDWARE SELECTION

For the preliminary prototype, a commercially available robotic lawnmower chassis was purchased and upgraded to meet the mechanical demands of mowing a typical lawn. The selected lawnmower was a Friendly Robotics RL500 [2]. This particular model was chosen for its small, compact size in order to simplify navigation and control.

To account for rough, uneven terrain the mower could face in some environments, the original Friendly Robotics drivetrain was upgraded. In order to have greater control and a zero turning radius, a differential drive method was selected. To achieve both needs, two 24 V DC wheelchair grade motors were selected. The motors will provide the mower with enough torque to traverse hilly terrain without the need for a complex external gear system such as the one found on the commercially available model. Since the original drive motors were much smaller than the upgraded versions, the base of the robot had to be modified to accept the additional size and mass of the new motors. A steel plate, shown in Figure 1 was fabricated to reinforce the plastic base. Moreover, the housing for the stock batteries was removed.

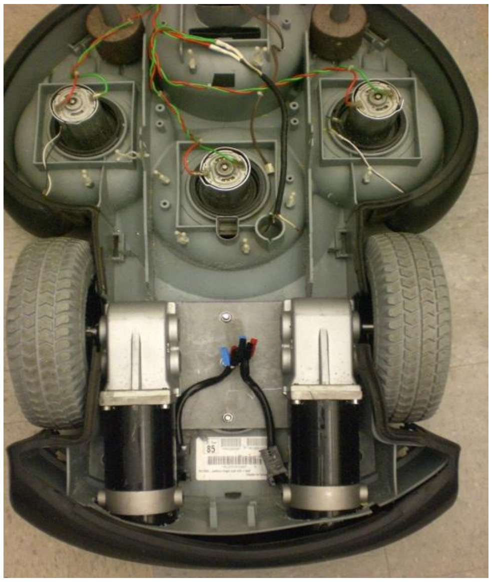

Figure 1. Mounting of upgraded drivetrain

Two 33 AH deep cell lead acid batteries were connected in series to provide the 24 V DC power source. By eliminating the mount for the stock batteries, it allowed for the selection of batteries with greater capacity. More energy storage was needed due to the greater power requirements of the drive motors and additional electronics. A Lexan box was fabricated and mounted to the top of the robot to house the new batteries.

Cutting of the grass is performed via the three 24 V DC that were originally on the RL500. These motors are designed to spin at 5,800 RPM and are adequate for the specifications of the project [3].

The robot is controlled using a single microcontroller in order to remain as simplistic as possible. The requirements for the microcontroller are very high. Several analog to digital converters, serial communication channels, and IO pins are needed. In addition, the processor must be fast enough to handle all of the required tasks in a reasonable amount of time. The selected microcontroller to fulfill these requirements is the LPC1768 [4]. While the LPC1768 met all the specifications required, it was also more attractive due to a rapid prototype board being commercially available [6]. This allowed for software algorithms to be developed for various peripherals while fabrication was being performed on the chassis. The processor itself is clocked at 100 MHz and contains a floating point unit enabling it to easily perform the calculations necessary for this project.

Great accuracy in navigation is needed for a professional style cut of the lawn. Most currently available robotic lawnmowers mow in an unintelligent manner until an obstacle is detected. This is undesirable because some portions of the lawn could remain uncut and is not an aesthetically pleasing method. To remedy this, a global positioning system (GPS) is used. The selected GPS device is the Trimble BD950 [5]. This solution was selected due to its small size, low power requirements, and high accuracy. However, due to the transmission delay, standard GPS is only accurate in the magnitude of feet. From a safety and aesthetic standpoint, this is less than ideal. To remedy this, two GPS receivers are utilized, one on the robot (rover) and one on a stationary base station. The two receives are connected via a radio link. They are then configured in real time kinematic (RTK) mode. The signals from the receivers are subtracted, thus reducing the overall error to roughly one inch. The BD950 receivers allow for setup in RTK mode and preform the necessary calculations onboard. The GPS receiver on the rover sends the corrected data over a serial line to the microcontroller.

As previously mentioned, the GPS receivers require a radio link between them. A Bluetooth modem on each receiver provides this necessary tie. Since the LPC1768 has multiple serial communications channels, the selection of Bluetooth for the wireless communication was due to ease of use. The selected modem is the BlueSMiRF RP-SMA [7]. This particular device was selected for its high data stream capabilities, (up to 115,200 bps), low power consumption, and long range.

III. HARDWARE DESIGN

Once the main components were selected, a system was designed to make the devices work in harmony. The power requirements for all electronic components had to be taken into consideration. Since most of the devices used require power from a 5 V source, a scheme was needed to step down battery power to 5 V and isolate the power supplies from the motors and electronics. Three separate power supplies are needed; one each for the microcontroller, GPS rover receiver, and motor optical isolation circuit. To solve this problem, three insulation type DC-DC converters were selected. These converters were selected due to no external design being needed, high efficiency (~80%), and small size [8]. To provide the necessary current to the GPS rover receiver and microcontroller, each circuit is powered by a 10 W converted. The optical isolation circuit is powered by a 2 W converter. In addition to stepping down the voltage to the required level, these converters also isolate each circuit's power supply from the main power source.

In order to prevent back EMF from interfering with the sensitive control electronics they must be isolated from both the drive and cutting motors. To achieve this, a NEC PS2811-4-F3-A four channel photocoupler is used [9]. However, the power capabilities of the LPC1768 are not great enough to drive the LED in the photocoupler hard enough. A basic PNP BJT transistor driver was constructed to remedy this problem. A P-channel device was selected because the port pins of the LPC1768 initialize high and it is desired to have no power supplied to the motors upon startup. Also, the current sinking capabilities of the microcontroller are greater than its sourcing capabilities. To attain the needed switching frequencies for the pulse width modulation (PWM) signal to be produced via the microcontroller, the load resistance of the photocoupler was selected to be 1 kΩ. This required a collector current of at least 4.7 mA. The current transfer ratio of the photocoupler is 200%. The LED is driven with 3 mA to allow for error. With a max forward voltage of 1.4 V, accounting for a V_{CE} of 0.3 V, a 500 Ω resistor is used to provide the LED with the required current. A complete hardware diagram can be seen in Figure 2.

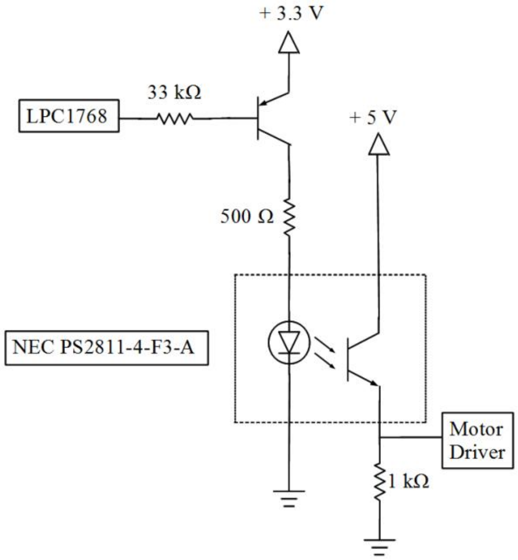

Figure 2. Circuit diagram for photocoupler with driver

A safety feature implemented for the operation of the lawnmower is the ability to switch the motors controlling the cutting of the grass on and off; both from the embedded software and remotely. This is achieved in the design using an isolated gate bipolar junction transistor (IGBT). A solid state solution was preferred over a magnetic device because of the high current requirements and availability of components. The IGBT also requires a very simple drive circuit. A Powerex CM400HA-24 was selected for our application [10]. The collector current for this device is rated at 400 A, well above that which is required by the cutting motors. This IGBT was donated by a Flanders Electric. In a commercial application, the collector current rating of the switch could be much less, thus significantly cutting the cost.

Another BlueSMiRF RP-SMA is utilized to remotely disconnect the power to the cutting motors. Using a handheld device equipped with a separate Bluetooth modem paired to the mower, the user is able to stop operation of the mower. As well as housing a kill switch, the handheld device contains a LCD screen that gives the user GPS and sensor information. The design for the IGBT isolator circuit was very similar to that of the PWM circuit. However, the gate of the IGBT requires a voltage of 7-20 V to turn on. To achieve this, 24 V are applied to the emitter of the photocoupler with an additional resistor to achieve the desired voltage range as shown in Figure 3.

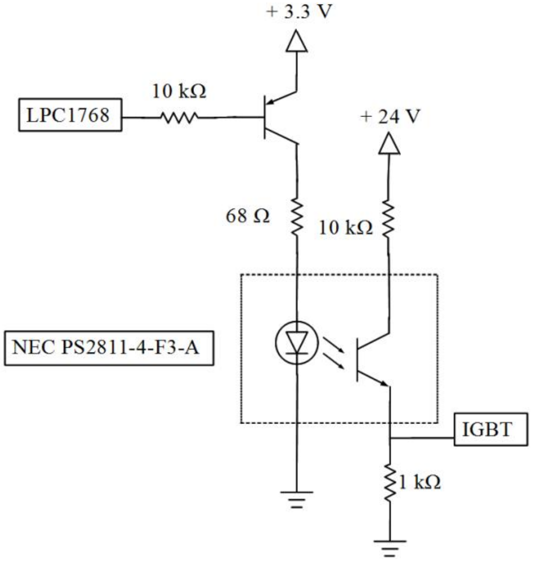

Figure 3. Circuit diagram for IGBT isolator

Obviously, the PWM signal produced via the microcontroller is not strong enough to drive the motors. To limit complexity, a commercially available motor driver was purchased. The selected device is the Dimension Engineering Sabertooth 2x25 driver [11]. As evident by the name, two 25 A circuits are onboard the driver. The Sabertooth can be configured to receive a standard RC PWM signal. In this convention, a signal high time of 1.0 ms will make the motor spin at full speed in reverse, 1.5 ms is neutral, and 2.0 ms full speed forward. A signal high time between 1.5 and 2.0 ms will spin the motors forward at a proportional slower place. This signal convention, shown in Figure 4, can be reproduced using the LPC1768. In addition, a radio capable of this convention was purchased, allowing the robot to be manually controlled, thus making transportation much simpler.

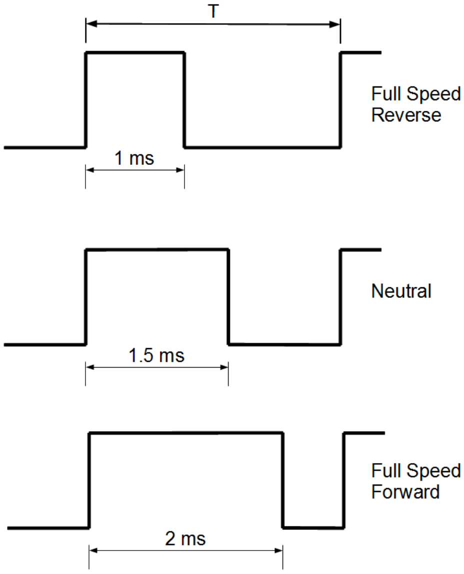

Figure 4. Standard RC pulses

Another safety issue, perhaps the most important, to be taken into consideration is the avoidance of obstacles. The RL500 originally comes equipped with both front and rear bump sensors. However, to accommodate the larger driver motors, the rear bump sensor had to be removed. The sensors are simply two pieces of metal separated by a small distance. When an item is "bumped" the two pieces come in contact, thus completing a circuit. The original front bump sensor is utilized in the design. The sensor is connected to a port pin on the LPC1768 that is continuously polled. This technique works well for large, static obstacles, but not for small or moving ones. In order to avoid these types of items, three ultrasonic sensors are mounted to the front of the robot. These sensors output an analog voltage that is proportional to the distance of an object. The resultant voltage of each sensor is sent to an analog to digital (A/D) converter on the LPC1786. The ultrasonic sensor selected is the MaxBotix XL-MaxSonar EZ3 [12]. This specific version was selected due to its medium range and narrow detection zone. A narrow detection zone was selected to limit cross interference between the sensors. To further limit interference, all sensors are triggered simultaneously using a microcontroller port pin. Since the upper range of the LPC1768 A/D converter is only 3 V, and the sensors are powered by 5 V, an inline voltage divider, as seen in Figure 5, was added to the output of each sensor to insure safe operation.

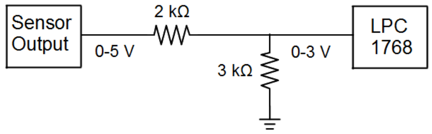

Figure 5. Voltage divider

Electrical interconnections are made via a two layer printed circuit board (PCB). To begin, a hardware schematic was created using ExpressSCH. Once completed, the schematic could be linked to a newly created .PCB file using ExpressPCB. In ExpressPCB, when a node is clicked, all other electrically connected nodes are highlighted, making trace layout much simpler. The PCB layout, complete hardware schematic, and images of the hardware can be found in Appendix I.

IV. SOFTWARE THEORY

As stated previously, the main control of the lawnmower is performed using the LPC1768 microcontroller. With a clock rate of 100 MHz, the LPC1768 has the computing power necessary to handle the requirements of this project.

The control software is broken down into a three part hierarchy shown in Figure 6. First, and most important, is safety. Before any control is performed, the microcontroller looks for a remote kill signal from the Bluetooth modem. If no kill signal is present, obstacle avoidance is performed. As mentioned above, the robot has two forms of obstacle avoidance. The bump sensors are used as a last resort. If the ultrasonic sensors miss an obstacle, the lawnmower will come into contact with the object and trip the bump sensor. The port pin that is connected to the bump sensor circuit is pulled low, and the microcontroller gives the motors the proper instructions to avoid the object.

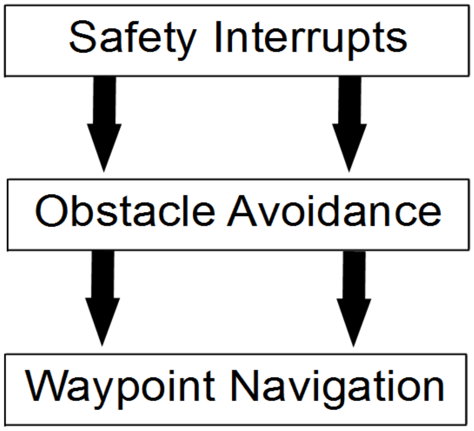

Figure 6. Algorithm hierarchy

The main form of obstacle avoidance is achieved via the ultrasonic sensors. A running average of the last several readings of each sensor is kept. Once one or more of these averages reaches a certain threshold, the microcontroller instructs the robot to wait for a predetermined time. If after that time the object is still in the path of the robot, the object is deemed static, and the appropriate maneuver is performed to avoid the obstacle. If the object is no longer present, the robot continues mowing on its present path.

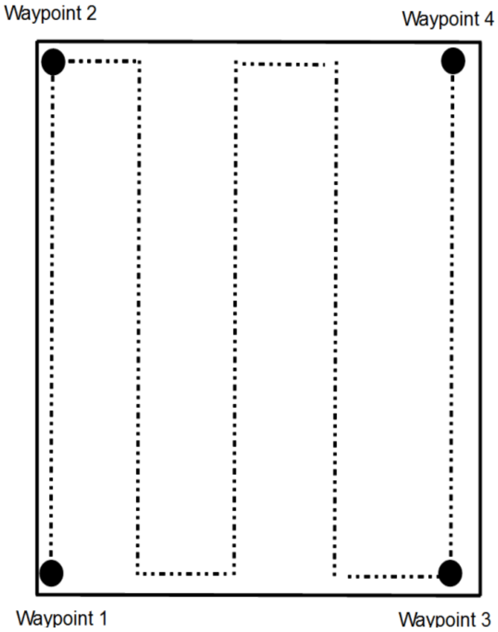

Figure 7. Waypoint explanation

Positional data is output by the GPS receiver in a GPGGA sentence. GPGGA is one of the many NMEA standards used in global positioning and provides all the information required for this project. All fields are delimited by commas. The first field is the time stamp used to synchronize the two receivers. The second is the degrees latitude, followed by minutes and decimal minutes and north or south. The third field is degrees and minutes longitude followed by east or west and the fourth is the quality of the GPS fix. The final field used is the fifth, and denotes the number of satellites currently locked.

Cartesian waypoints were chosen to provide beginning and ending points of a line segment which denotes the desired path of the robot. The outer four corners of the area to be cut are manually stored in the robot, which are the first four points it navigates to. Upon finishing its initial path, the robot then dynamically generates waypoints parallel to the first two waypoints at a distance equal to the robot's width.

As shown in Figure 8. Distance , take (x_1, y_1) as the beginning point and (x_2, y_2) as the ending point with (x_0,y_0) as the robot's current location. Equation 1 will give the distance, d from the robot to the closest point on the desired path. Error from the path is calculated using this equation and allows control in both the x and y directions. If the error is near zero, both of the robot's wheels will travel forward at a defined target speed. If the error is more significant, the software PID controller then adjusts the left and right wheels from the target speed in order to minimize the error.

$$d = \frac{|(x_2 - x_1)(y_1 - y_0) - (x_1 - x_0)(y_2 - y_1)|}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$$

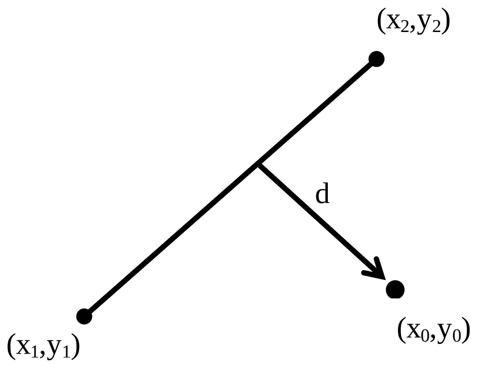

Figure 8. Distance illustration

V. STANDARDS AND CONSTRAINTS

Throughout the design and construction of this project, the following standards were utilized:

Standard	Description	Use
Recommended Standard 232	Serial, binary communication	Communication between GPS receiver and LPC1768
Bluetooth	Open standard wireless serial communication	Communication between rover and base station GPS receivers Communication between handheld terminal and LPC1768
IPC-2221	Generic Standard on Printed Board Design	Used as baseline for motherboard design
GPS Real-time kinematic	Subtracts error in standard GPS signal by using two receivers	Used to achieve desired accuracy
NMEA 0183 Standard	GPS sentence format	Interpret GPS data

The constraints for this project were numerous. As mentioned previously, safety was used as a requirement in all aspects of the design. All of the original safety features of the RL550 robot were incorporated into this project, as well as additional measures such as a remote kill switch. Also, as an environmental constraint, a conventional internal combustion engine was not used due to the harmful emissions it emits. Because of this, the size of the batteries needed to drive the mower was increased due to electric motors being needed for the cutting of the grass. Finally, manufacturability was taken into consideration. The original robot was altered all little as possible. This was done because most likely, Friendly Robotics has a standard manufacturing process for the RL550. Keeping most of the original mower intact would allow a manufacturer such as Friendly Robotics to easily produce our version of the lawnmower.

VI.COSTS AND SPECIFICATIONS

Costs

Friendly Robotics Chassis	$500.00
mbed microcontroller	$60.00
Custom PCBs	$166.00
2 24V electric motors	$75.00
Various electronic components	$120.00
Sabertooth driver	$125.00
2 12V, 33ah lead acid batteries	$160.00
BD950 GPS receiver	$4,000
Ultrasonic sensors	$40.00
TOTAL:	**$5,246.00**

Specifications

Max speed	2 MPH (software limited)
Length	36”
Width	26”
Height	28”
Weight	120 lbs
Sabertooth driver	$125.00
Energy usage (max)	800 watts
Energy usage (typical)	500 watts
Cutting time	1 hour

VII. CONCLUSION

Throughout the hardware design, great care was taken to select the simplest, most cost effective method for solving each design challenge. The result is a solution that is capable of completing the task of mowing a simple lawn. While the hardware design and fabrication has been finalized, more work in the area of software development must be performed to complete the system.

VI. FUTURE WORK

Although the result of this project is a lawnmower that is environmentally friendly, the robot’s batteries must still be charged using electricity that may have been produced using fossil fuels. To remedy this, a solar powered charging system could be added with an algorithm to the software hierarchy that will instruct the robot to travel to the charging station when the batteries reach a minimum threshold. In addition, the prospect of using a sophisticated GPS unit such as the BD950 is impractical due to its high price tag. Work must also be done to limit the expense of the current navigation system without sacrificing accuracy.

VII. REFERENCES

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APPEXDIX I.

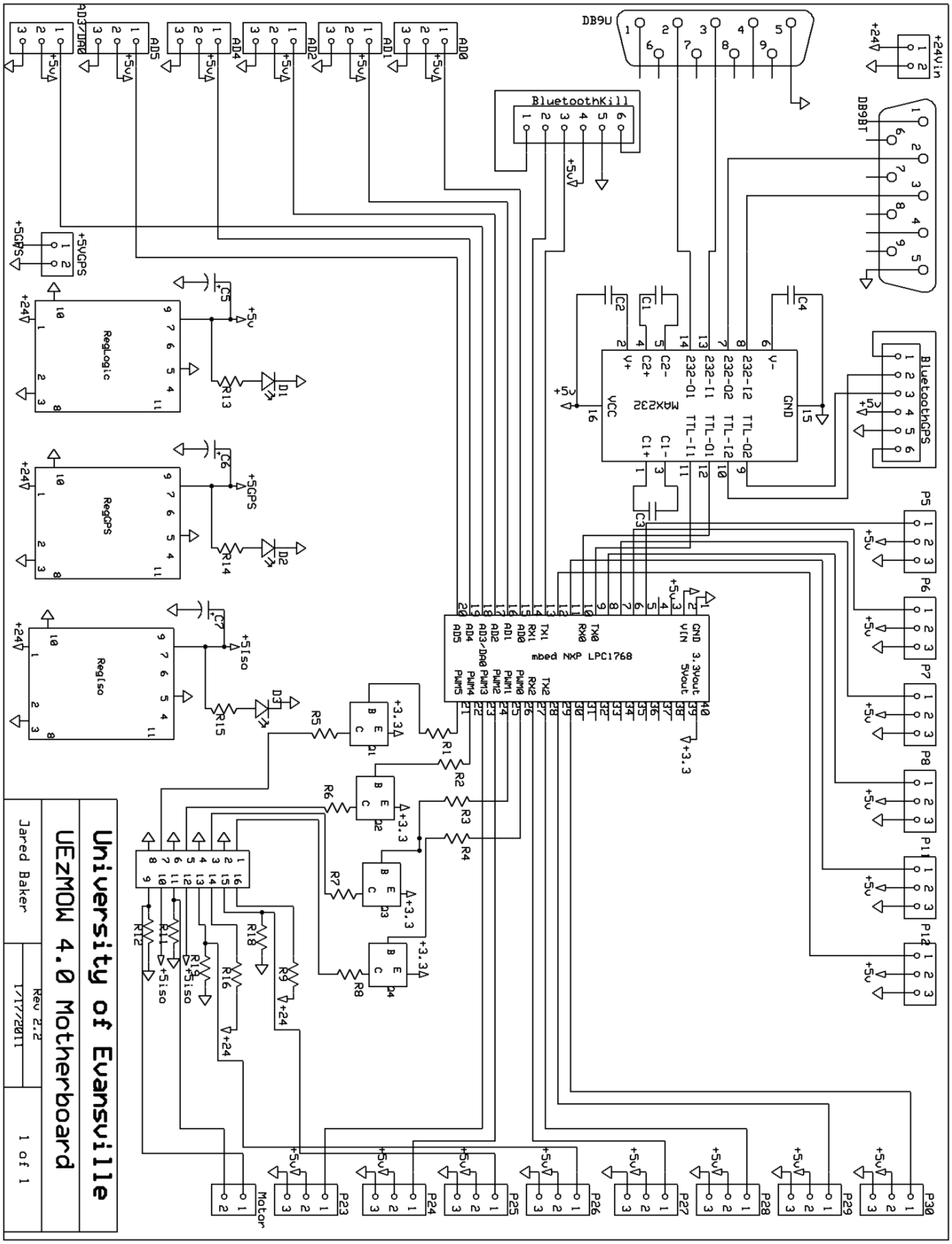

Figure 9. Complete Hardware Schematic

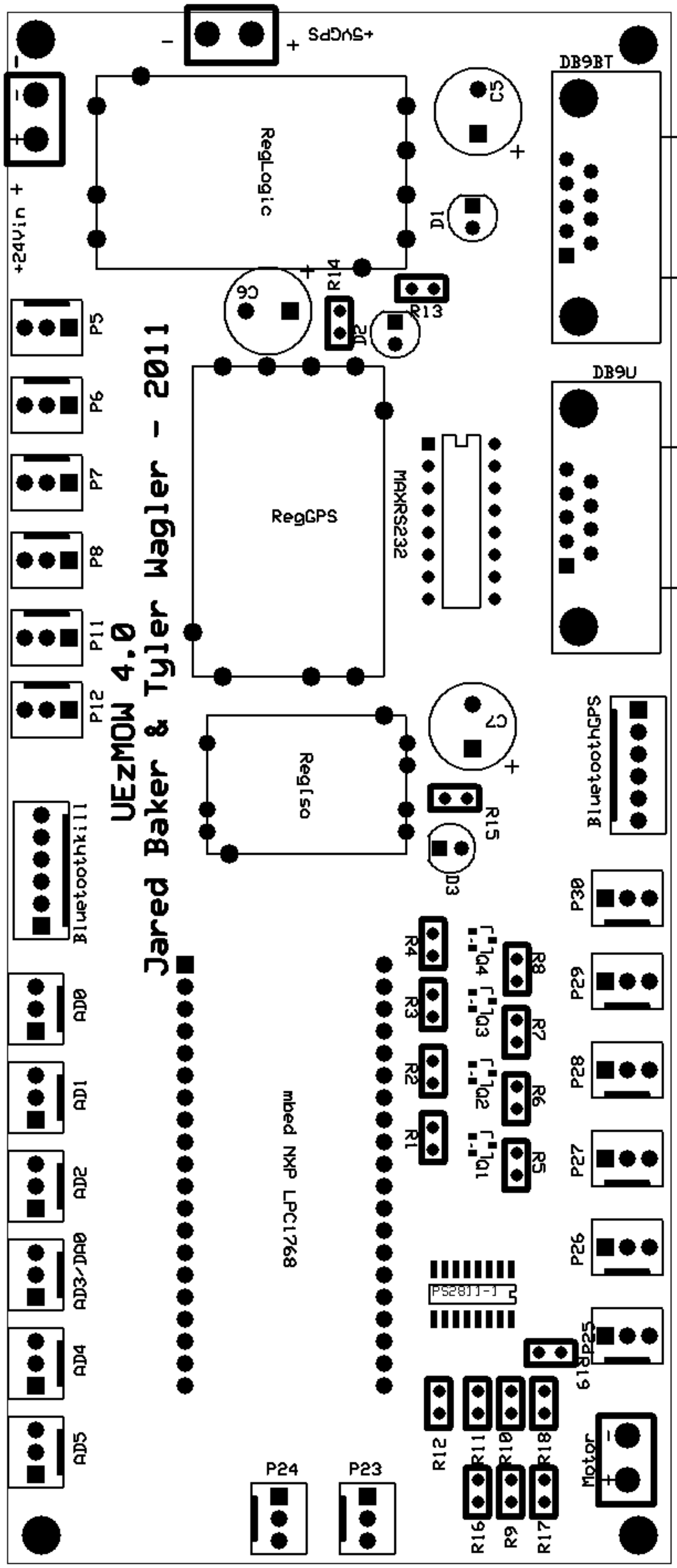

Figure 10. Printed Circuit Board Layout

1. Ultrasonic sensors
2. Front bump sensor
3. Rover GPS antenna
4. Lead-acid batteries

Figure 11. Completed hardware

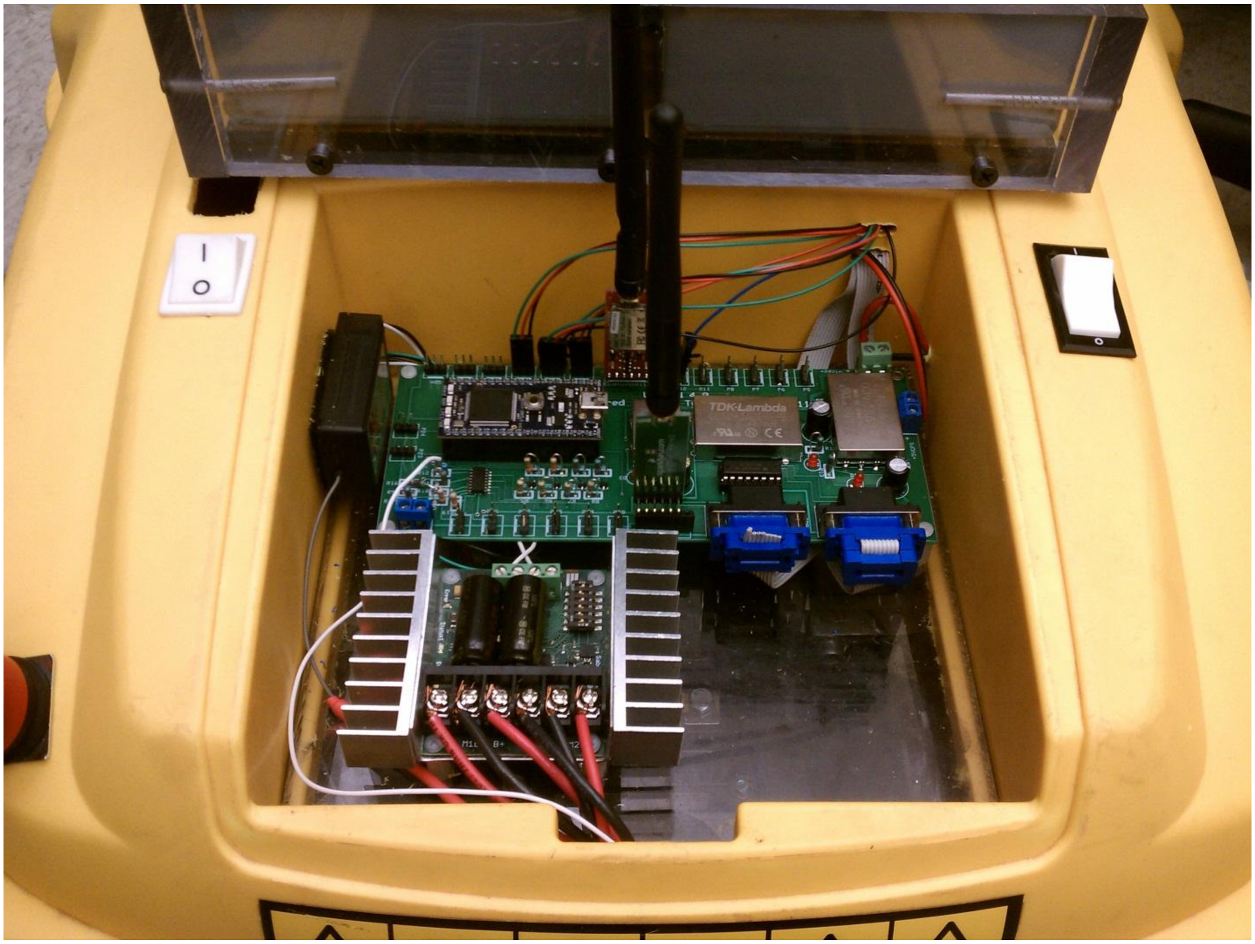

Figure 12. Control hardware