

UEzMOW 3.1.1

Autonomous Lawn Mower

Technical Design Report

The 7th Annual ION Robotic Lawn Mower Competition

June 3 - 5, 2010
Beavercreek, Ohio



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Introduction

UEzMOW 3.1.1 is proud to be the University of Evansville's entrant into the 7th annual ION Robotic Lawn Mower competition. The current version is an upgrade of UEzMOW 3 designed to compete in the ION Robotic Lawn Mower competition. The main goal of this revision was to upgrade UEzMOW 3 in the areas of object avoidance and user friendliness. Inspired by the words by William of Occam, "it is in vain to do with more that which can be done with less" great lengths have been taken to insure the challenges set forth by this project have been solved in the simplest way possibly. Two major upgrades over UEzMOW 3 include the use of more robust ultrasonic object sensors and the ability to program the main microcontroller as well as monitor the robot's progress using a wireless Bluetooth connection.

Team Overview

The UEzMOW 3.1.1 project consisted of two student members. Additional support was provided by University of Evansville EECS facility. Student members, as well as major and specialties were:
Jared Baker, Electrical Engineering, Hardware Design
Tyler Wagler, Computer Engineering, Software Design

Hardware Design

Safety

Safety is priority number one in this project. UEzMOW 3.1.1 is equipped with multiple layers of safety devices as well as configured to be "fail safe" to ensure everyone in the area of the robot remained unharmed. These safety features will be discussed in further detail in the relay section. Safety decals, similar to those seen on commercial lawn mowers, were added as an update from UEzMOW 3.

To insure fail-safe operation, port pins on the main microcontroller are continuously polled for a kill signal from a RF remote kill switch. Should the microcontroller receive a kill signal, all peripherals, including the gasoline engine and drive motors, will cease operation.

To prevent the robot from running out of control, software continually verifies that the robot is still within the borders of the course. If it enters the surrounding safety zone, the blades are turned off and the robots route is altered so that it returns to the main course where the blades will be turned back on. If the robot ventures too far, software will disable both the blade motors and drive motors and wait for a restart.

A large red emergency stop button is located on the rear of the mower. Should this button be pressed, electrical power distribution to the mower will be terminated, ceasing operation of the drive motors and gasoline engine.

Mechanical

The mechanical systems from UEzMOW 3 were carried over and used in UEzMOW 3.1.1. The mower consists of two main 10" drive wheels with two rear caster wheels to provide stabilization and a more even cut while mowing. The mower is capable of turning with a zero degree radius. The mower deck was custom designed and manufactured. It was designed with a square front to simplify obstacle detection. A 7.5 horsepower, vertical shaft, Tecumseh gas powered internal combustion engine was directly connected to the mower blade for maximum cutting power in tall, thick grass. System electronics were housed in a custom build Lexan box.

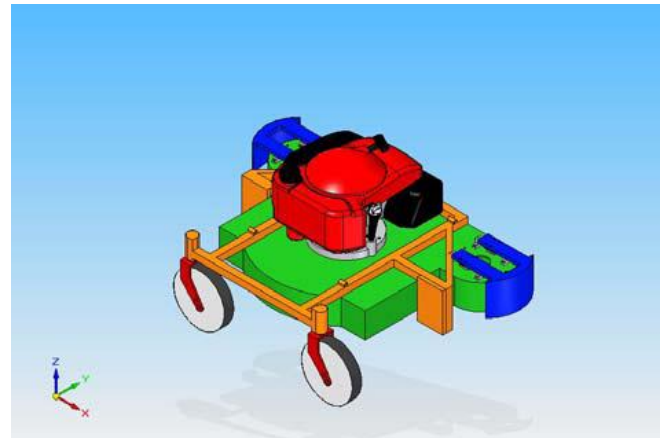


Figure 1 UEzMOW 3.1.1 Rendering

Navigation



Figure 2 Trimble BD950 GPS Receiver

Navigation on UEzMOW 3.1.1 is also carried over from UEzMOW 3. Two Trimble BD950 GPS receivers give UEzMOW 3.1.1 positional accuracy to 2 cm. The BD950 can be used in standalone, differential, or Real-Time Kinematic (RTK) modes. To get the accuracy needed for this application, we have chosen to use the GPS unit in RTK mode. This mode requires that the user not only have a GPS unit on the machine, but must also setup a base station from which distance and phase

calculations can be performed in order to increase the accuracy of the GPS. In order for proper functionality, the two GPS receivers must have five common satellites and some form of communication between themselves. The specification for the BD950 in RTK low latency mode calls for a radio modem that can transmit standard RS232 data at a baud rate of at least 9600 bps. We have fulfilled this requirement by using two BlueSMIRF 100 meter Bluetooth wireless modems in a slave/master configuration. Upon power up, the base station will automatically connect to the processor designated to receive GPS data. Finally, we found the only hardware

required to interface with the BD950 was a standard Rs232 serial port and a processor capable of handling the amount of data received.

Ultrasonic Sensors

Obstacle detection, both static and dynamic, is accomplished using two SensComp 6500 Series Ranging Modules mounted on each side of the front of the lawn mower. These modules drive a 50 kHz electrostatic transducer. These sensors were selected due to their ability to filter out high frequency noise generated by vibrations from the gasoline engine.

Motors and Drivers

UEzMOW 3.1.1 is propelled using a differential drive configuration. To achieve this, a separate motor must be used to power each of the drive wheels. Two 24V, wheelchair grade DC electric motors give us both the requirements to configure a differential drive as well as enough power to navigate the required terrain.

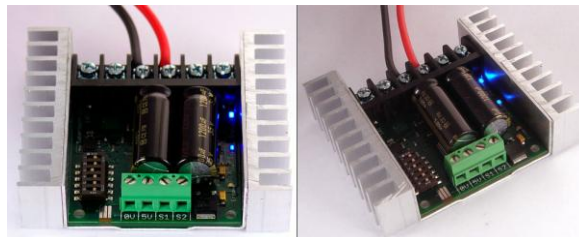


Figure 3
Sabertooth 2X25 Motor Driver

This drive configuration also increases the complexity of the drive circuitry needed to propel the motors. To solve this problem, we used what is commonly known as a dual H-driver. Due to the power requirements of the selected motors, we opted to purchase a prebuilt driver. The chosen driver was the Sabertooth Dual Channel Motor Controller. It is rated at 24 VDC and can handle a constant current of 25A, well surpassing the requirements for the motors used. An additional feature of this driver is that it supports regenerative drive, which means when stopping or going downhill it will use the resistive energy of the motors to charge the batteries. It also contains a 5V power supply. The driver requires an RC type input.

Electrical Power System

UEzMOW 3.1.1 utilizes two 12V (33AH) lead acid batteries in series to provide electrical power in order to power everything on the lawn mower except the main cutting blades. Battery charging takes 3.5 hours. The 24V source from the two series connected batteries is used to power the main drive motors. The source is then regulated down to one 12V and two 5V supplies. The two 5V supplies are used for the logic power on the microprocessor boards as well as the GPS receiver. Using a TDK-Lambda CC6-2405 chip, both 5V supplies are completely isolated from the 24V side of the circuit. Isolation is needed to remove motor noise from the logic power/ground buss. This kind of noise can corrupt analog data and cause the processors to reset. Magnetic isolation chips (ADuM1400) on the PC boards complete the isolation between our logic outputs and the h-drivers. The 5V non-isolated supply on the Sabertooth controller board is used to power the magnetic isolators. It was determined running 24V to

the main drive motors made them difficult to control in autonomous mode. However, running the motors in 24V mode was still desired for RC mode. For this reason, a SPDT was added to change between 12V and 24V modes.

Relays and Relay Drivers

Several 12VDC mechanical relays are located on UEZMOW 3.1.1. These relays are automotive grade and rated for 24VC at 30A on the secondary, making them suitable for our application. Each relay is used for a specific task:

Remote Kill - Controls power to motors. When this relay is not charged, (NO) there is no 12V supply going to the Sabbertooth driver. This is a SPDT relay located inside the main controller box.

Engine Enable - When this relay is not charged, the spark plug to the motor is tied to GND thus eliminating the possibility for the engine to start. This relay is a DPDT. When energized, the GND to the spark plug is removed and the Engine Start Relay is tied to 12V.

Engine Start Relay - When not energized, the starter motor on the engine is tied to 12V.

Notice the starter motor on the engine cannot be turned on until after the engine has been enabled. This allows for another layer of safety. Also, notice all of the relays are in a fail-safe configuration. In each case, if the processor would reset or power would be lost, all systems will shutdown.

CPUs and Peripherals

Keeping simplicity in mind, UEZMOW 3.1.1 is controlled simply by using two 8-bit microcontrollers. The main processor and workhorse of the system is an at89c51ed2. This chip was selected because of its extended IO and additional memory space. The second processor (preprocessor) is an at89c51rd2.

The preprocessor is connected to the GPS unit via a standard uart to the main processor via an 8-bit data bus and two interrupt pins. The interrupt pins are used by software to create an interrupt driven 8-bit bidirectional parallel port with handshaking.

The main processor board has a standard UART for debugging and programming, an 8-channel pseudo flash A2D converter, and a LCD. New for this year, a Bluetooth modem has been added to UEZMOW 3.1.1 giving us the capability to program and debug without the need to plug in a serial cable. Also, a 2-channel magnetic isolator is used to connect to the motor driver. Most other devices such as the Remote Kill module are connected using standard IO pins. A 16-pin header is used to connect the main processor to the preprocessor via the interrupt driven 8-bit bidirectional parallel port referred to earlier.

Software Design

As stated previously, UEZMOW 3.1.1 contains two separate onboard microcontrollers to perform all functions required. Below is a detailed description of the tasks of both the preprocessor and the main processor.

Preprocessor

Also stated previously, the preprocessor is an at89c51rd2. The main function of the preprocessor is to receive GPS data and convert it into a form that is usable for the robot. Since we have chosen an 8-bit microcontroller, this task is a little more difficult. For our application, we have selected to use a GGA NMEA sentence. This sentence contains a large amount of information. However, only a small portion of what is received is needed for our application. Currently, the only information from the sentence we are capturing is the latitude and longitude data.

The first thing the preprocessor must do after receiving data is to parse the data out so we can receive the information relevant to our task. Once this has been done, we need to determine how much of the data we really need. We have determined only a very small part of the decimal value of the latitude and longitude data is needed for our function. Because of this, the applicable data is pulled out while the remainder is discarded. After all, we need to know where we are in the yard, not on the planet.

Next, the data needs to be adjusted so that it can be localized into our “local” coordinate system. Since the contest course will most likely not be perfectly square with relation to latitude and longitude coordinates, a rotation must be performed so that only one direction (longitude or latitude) is changing while the lawn mower is following a straight line. To do this on an 8-bit processor, we must first calculate some constants to avoid using floating point arithmetic.

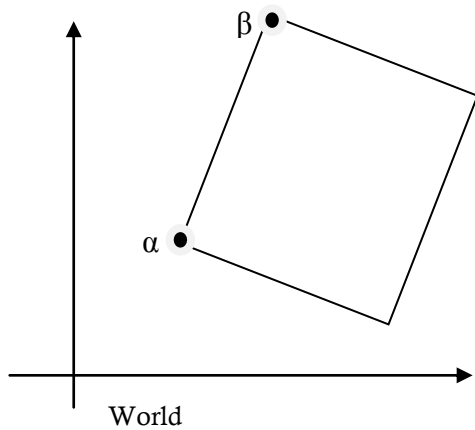


Figure 4 Sample Course

First, we must calculate the distance between α and β . This is easily performed using the Pythagorean Theorem ($a^2 + b^2 = c^2$) or

$$R = \sqrt{\Delta x^2 + \Delta y^2}$$

Equation 1 Pythagorean Theorem

Where Δx is the difference in x between α and β and Δy is the difference in y between α and β .

Using R , Δx and Δy , the $\cos(\theta)$ and $\sin(\theta)$ is easily calculated using the trigonometric identities show is Equation 2 and Equation 3.

$$\cos(\theta) = \frac{\Delta x}{R}$$

Equation 2 Definition of Cosine

$$\sin(\theta) = \frac{\Delta y}{R}$$

Equation 3 Definition of Sine

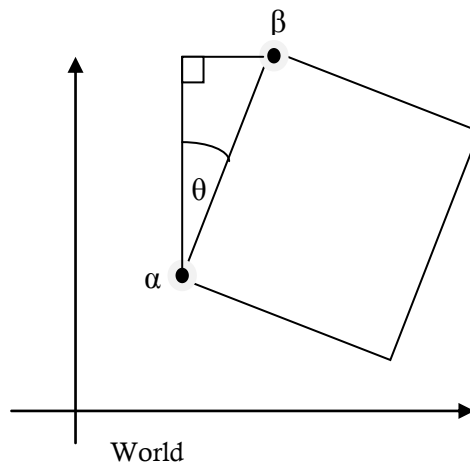


Figure 5 Sample Course with Rotation Shown

Using these calculations, we arrive at two floating point numbers that when used in the correct equation, will rotate β about our local origin (α) so that β is placed directly above α , thus placing β on the local y-axis at a distance of R .

Rotation of Points based on the angle θ above:

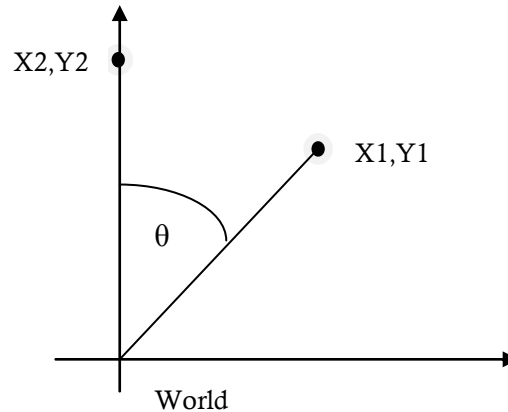


Figure 6 Example Point Rotation

For example, say we want to rotate point $(X1, Y1)$ by θ to point $(X2, Y2)$

$$x_1 = R * \cos \theta$$

Equation 4

and

$$y_1 = R * \sin \theta$$

Equation 5

So:

$$x_2 = R * \sin(\theta - \theta) \rightarrow R[\sin\theta\cos\theta - \sin\theta\cos\theta]$$

Equation 6

and

$$y_2 = R * \cos(\theta - \theta) \rightarrow R[\cos\theta\cos\theta + \sin\theta\sin\theta]$$

Equation 7

But using Equation 4 and Equation 5, by substitution:

$$x_2 = x_1 \cos\theta - y_1 \sin\theta$$

Equation 8

and

$$y_2 = y_1 \cos\theta + x_1 \sin\theta$$

Equation 9

Finally, Equation 8 and Equation 9 can be used to rotate each point into the local coordinate system using the two constants derived earlier.

After the new GPS coordinates have been created, the preprocessor then sends them to the main processor using the 8-bit parallel port on the data bus.

Main Processor

As UEzMOW 3.1.1 maneuvers through the course, the high level control algorithm considers a multitude of factors with varying priorities when determining the next robotic action. These factors consist of the robots position with respect to boundaries of the course, the robots desired path, and potential obstacle blocking this path. Some factors have priority over others. For example, it is much more important to avoid running someone or something over than maintaining a straight path. Considering these priorities, the main processing loop contains a hierarchy of control algorithms, which can be seen in Figure 7.

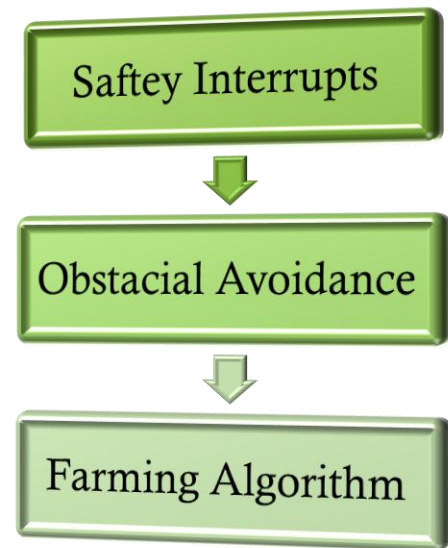


Figure 7 Algorithm Hierarchy

Safety

As pointed out earlier in the hardware section of this document, all of the hardware has been designed to be fail safe, meaning if the processor should fail or be reset, all of the peripherals should stop, including the drive motors and the engine. UEzMOW 3.1.1 is also equipped with a remote kill switch that can stop all of these functions with the push of a button. This kill switch is simply connected to four port pins on the main processor. These port pins are continuously polled. If the kill signal is produced, the processor simply turns off the engine and drive motors.

Object Avoidance

Using the ultra-sonic sensors described earlier, UEzMOW 3.1.1 is capable of navigating the field without coming into contact with any foreign objects. The PCA on the preprocessor is used to calculate the high time of a signal received from the ranging modules. A running average is calculated. When the running average reaches a certain threshold, the preprocessor sends the main processor an “object detected” command and the main processor acts accordingly.

Conclusion

Costs

Description	Unit Cost	Quantity	Price Paid	Retail Total
7.5 HP Tecumseh Engine	\$160.00	1	\$160.00	\$160.00
24V Electric Motors	\$200.00	2	\$400.00	\$400.00
12V (33 AH) Lead Acid Battery	\$75.00	2	\$150.00	\$150.00
Trimble BD950 GPS receiver	\$10,000	2	\$4,000	\$20,000
Sabertooth 2X25 Motor Driver	\$125.00	2	\$250.00	\$250.00
Chassis materials		Various	\$250.00	\$250.00
SensComp Ultrasonic Sensors	\$64.00	2	\$128.00	\$128.00
Electronics		Various	\$200.00	\$200.00
			Total Paid:	Total Retail:
			\$5,538	\$21,538

Max Speed

The maximum speed of the lawn mower in ideal conditions is 1.7 MPH.

Physical Specifications

Specification	Number	Unit
Overall Width	36	in
Track Width	35	in
Cutting Width	22	in
Overall Length	36	in
Wheelbase	16	in
Height	30	in
Weight	200	lbs
Drive Wheel Diameter	10	in
Drive Wheel Width	1.75	in
Drive Wheel Diameter	8	in
Drive Wheel Width	1.75	in

Operating Time

The limiting factor on operating time for the lawn mower is the gasoline engine. The engine is capable of running for 43 minutes under a light load.