

UC Robomow 2009

Technical Report

**ION Robotic Lawnmower Competition
Beavercreek, Ohio
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University of Cincinnati
College of Engineering

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1 Overview

1.1 Team Organization

This is the first year the University of Cincinnati has participated in the ION Robotic Lawn Mower Competition. Our team consists of four students and one advisor, all of which have electrical engineering backgrounds. We divided into two subgroups with one focusing on hardware integration and the other focusing on software design. After our preliminary design work was complete, the two subgroups merged, and system level integration and testing was approached as one team.

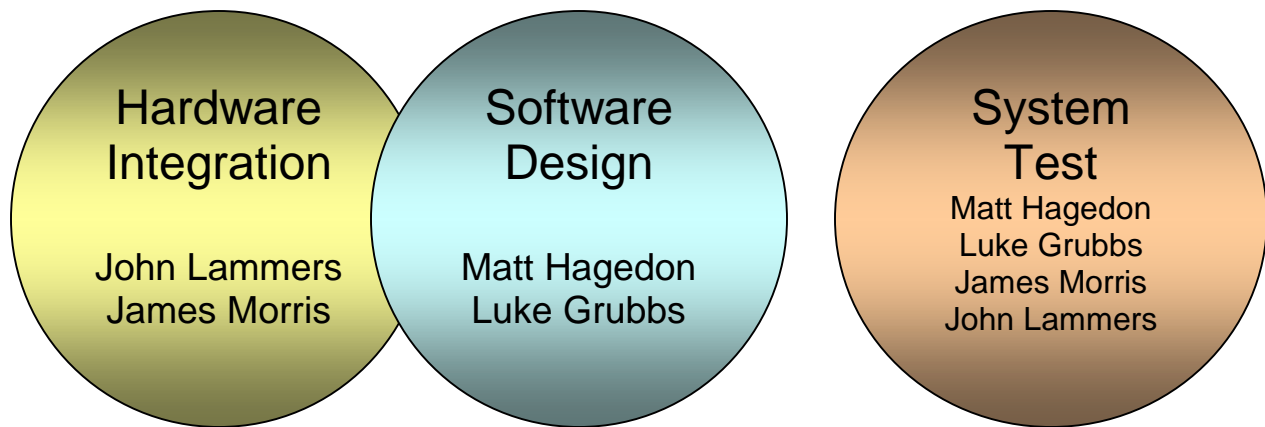


Figure 1.1.1 The hardware integration and software design subgroups and their members are depicted above. The two subgroups combined to approach system level integration and testing as one team.

1.2 Lawnmower Design

We chose to use the Friendly Robotics RL850, a commercially available autonomous lawnmower, as our team's lawnmower design due to its strong upside. The RL850 provides all of the functionality needed to mow a yard, namely navigation with zero turn radius and blade control, which eliminated the mechanical design work and allowed our team of electrical engineers to focus on the electronic design and control logic. Although it was built to operate in autonomous mode, the RL850 can operate in manual mode, which relies on the user to provide commands to the mower through a hand held controller. Our design will use the RL850 in manual mode and replace the user's input to the controller with a custom designed control system fixed on the hood of the RL850.

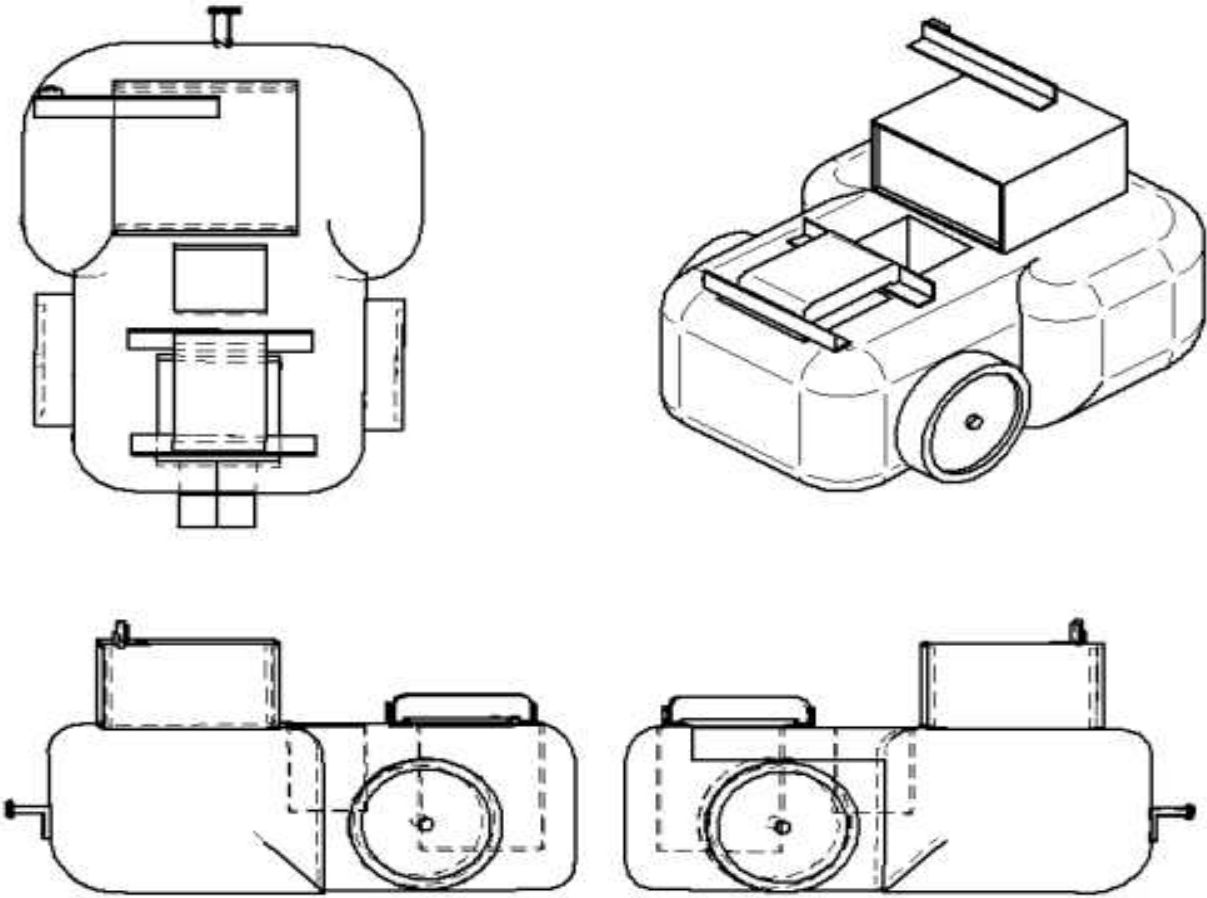


Figure 1.2.1 Preliminary design of the UC Robomow 2009 robotic lawnmower



Figure 1.2.2 Front view of UC Robomow 2009



Figure 1.2.3 Back view of UC Robomow 2009

2 Electronic Design

2.1 Main Control Unit

The main control unit consists of a PIC32 micro-controller and a Zotac NF610 IDE with Core2Duo. The PIC32 is used to send control commands to the RL850 over a parallel I/O port as well as interface with the digital compass, sonar, and IMU.

The PIC32 interfaces with the digital compass and sonar over an inter-IC (I2C) bus and the IMU over the universal asynchronous receiver/transmitter (UART).

The PC is used to handle data from the sensors that require heavy data processing, such as the web cam and GPS. The PC interfaces with both the web cam and GPS over a universal serial bus (USB).

The PIC32 and PC exchange data over a UART-to-USB converter.

2.2 Sensors

The sensing system consists of a global positioning system (GPS), an inertial measurement unit (IMU), a digital compass, a sonar unit, and a web cam.

The GPS unit used in our control system is the San Jose Navigation FV-M8, which supports DGPS operation with up to 2.6m accuracy. We have configured the unit to operate with an update rate of 5 Hz and a baud rate of 38400Bd. The FV-M8 supply voltage is 3.3-5V, however, we are using an evaluation board that allows us to both power and communicate with the device via USB.

The IMU used in our control system is the Atomic IMU 6DOF, which is hardwired to the PIC32 micro controller using a UART interface with an update rate of 1Hz and baud rate of 200Bd. The IMU achieves six degrees of freedom using a Freescale MMA7260Q TM triple axis accelerometer with up to 6g sensitivity and three ST Microelectronics LISY300AL TM single axis 300°/s gyros.

The digital compass used in our control system is the Devantech R117, which interfaces with the PIC32 micro controller on an I2C bus. The compass offers 0.1° resolution with up to 3° accuracy at an update rate of 5Hz and a baud rate of 115200Bd.

The GPS, IMU, and digital compass are used to provide position information to the controller. The lack of accuracy in the sensors is compensated for by integrating

the sensors using a Kalman Filter, which will be discussed in more detail in the Software Strategy section of this report.

The sonar unit used in our control system is the Devantech SRF10 Ranger, which interfaces with the PIC32 micro controller on the I2C bus at an update rate of 5Hz and a baud rate of 115200Bd. Ranging is done using a fully timed echo, and results are reported in millimeters. The sonar's sole responsibility is to inform the controller of obstacles in the lawnmower's path.

The web cam used in our control system is the Logitech QuickCam Pro, which interfaces with the PC via USB and is capable of capturing thirty frames per second. The web cam is used to detect and track the white lines surrounding the perimeter of the mowing area.

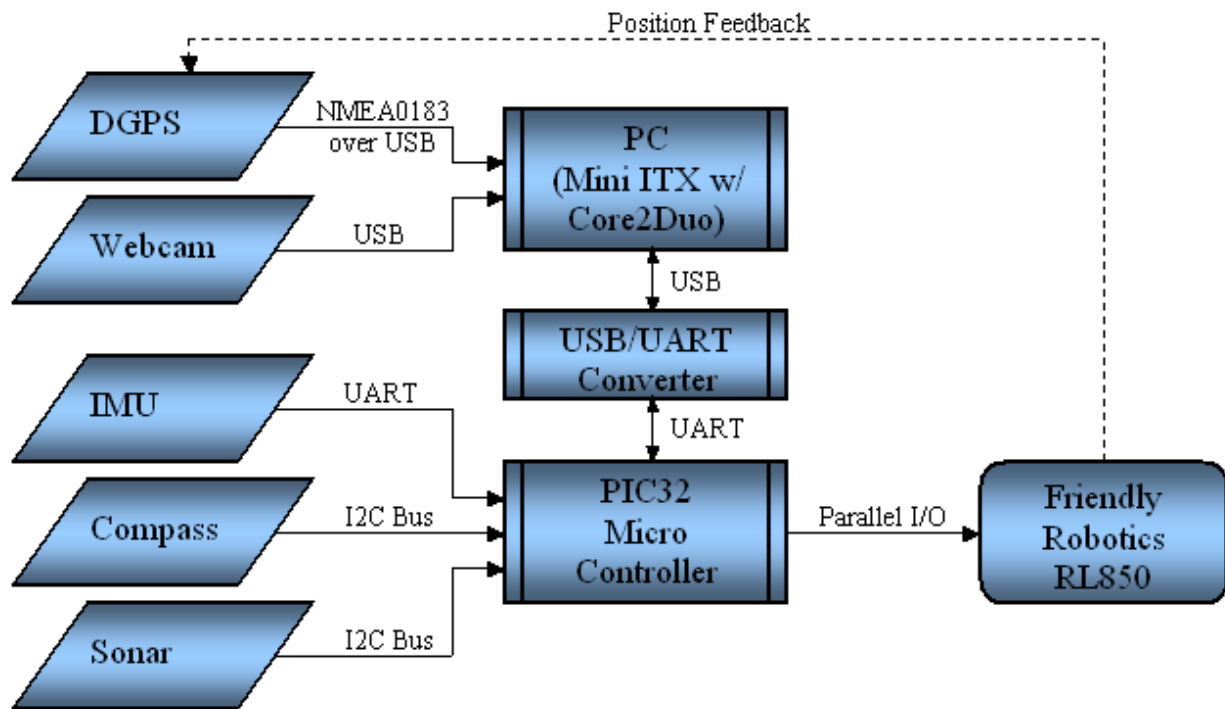


Figure 2.2.1 UC Robomow 2009 hardware design diagram

2.3 Power System

A 24V sealed lead acid (SLA) battery is used to drive the three 150W motors on the RL850 and all electronic components in our custom control system. The average charge time is twenty hours while the average operation time per charge is three hours.

3 Software Strategy

3.1 Overview

There were a number of different programming languages used to drive the various components from a software perspective. The PIC32 was coded in C, the PC in C#, and many of the algorithms we used were coded in MATLAB. The main control program is event driven and runs in a C# environment on the PC. The events driving the mower's activity are based on the vision algorithm and path-planning algorithm used.

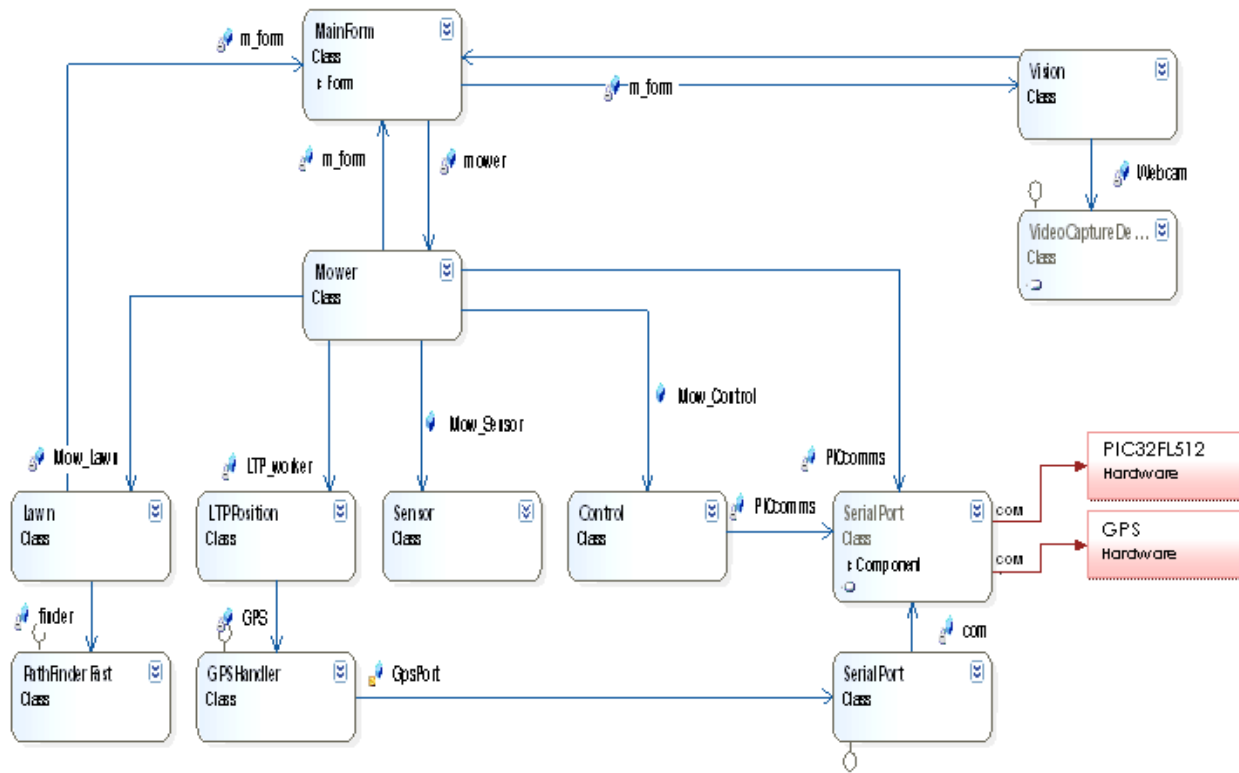


Figure 3.1.1 UC Robomow 2009 software design diagram showing the interaction between software classes

3.2 Vision Algorithm

The vision algorithm uses the Logitech QuickCam Pro to detect and track the white lines surrounding the mowing area. When the web cam captures a frame, it is sent to the PC for processing. In order to extract the necessary data from the captured frame, a Matlab transform and a Hough transform must be implemented. The MATLAB transform changes the rectangular image into a trapezoidal image in order to compensate for the angle at which the Logitech QuickCam points towards the ground, and the Hough transform is used to identify visible lines.

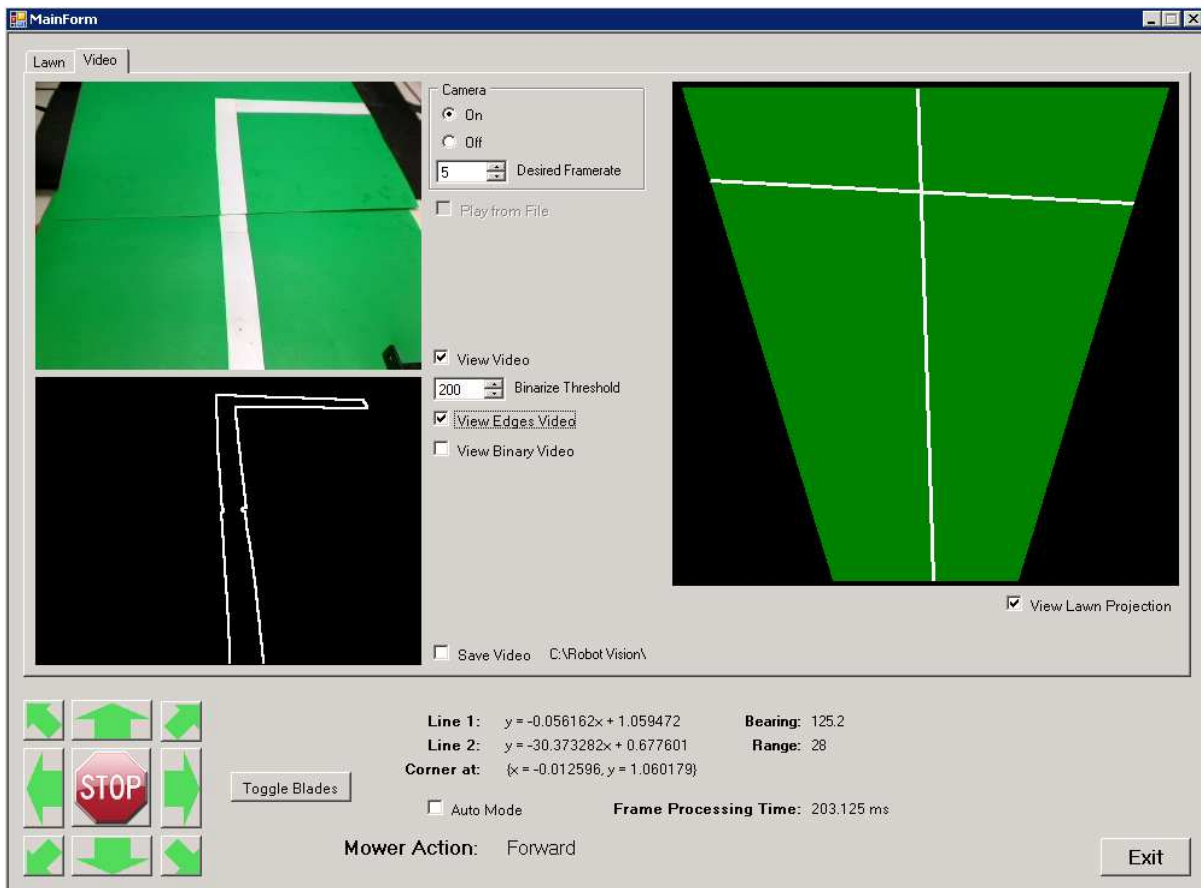


Figure 3.2.1 A screen shot of the graphical user interface (GUI) while debugging video in a simulation environment. Image results from the Logitech QuickCam Pro (top left), the Hough transform (bottom left), and the Matlab transform (right) are shown.

Once the lines are detected, the mower will execute an algorithm pertaining to the state (lawn discovery, border detection, or mow rows) that the lawnmower is in. The lawn discovery state is used at the start of a mowing session to enter the mowing area. Once the mower enters the lawn, the border detection state is used to mow the perimeter of the lawn and log GPS waypoints. After mowing the

perimeter of the lawn, the lawnmower switches to the mow rows state and the path-planning algorithm is invoked.

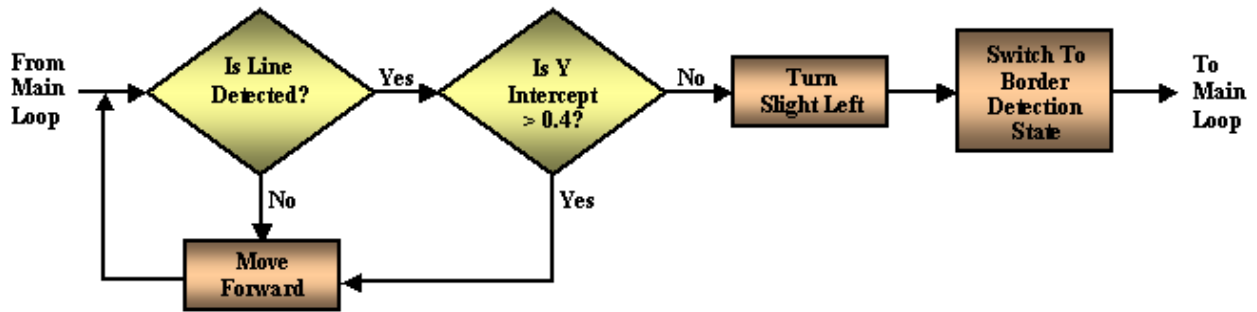


Figure 3.2.2 Lawn discovery logic diagram

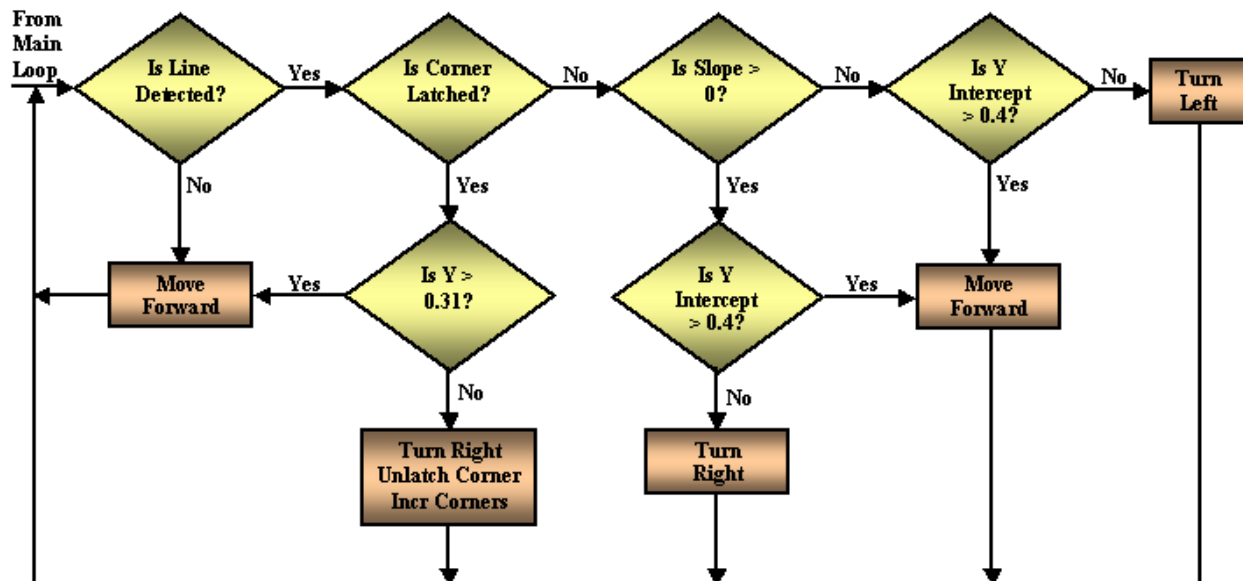


Figure 3.2.3 Basic border detection logic diagram; the advanced border detection algorithm will implement slight right/left movements if the slope of the line is large

3.3 Path Planning

Path planning is achieved by breaking the mowing area into a grid of 0.5m^2 squares and placing an objective point at the end of the first row of the mowing area. The A* algorithm is used to develop a dynamic path to each objective point by assigning scores to the squares surrounding the current square and instructing the lawnmower to move to the surrounding square with the lowest score. The score assigned to each square consists of the sum of two terms, one of which biases the square while the other term is heuristic. A mowed square will receive a higher

biasing term than an un-mowed square promoting movement to un-mowed areas of the lawn. The heuristic term is determined using the Manhattan method, which estimates the number of moves from the square to the objective point. Any square that has been identified by the sonar as containing an obstacle will not be assigned a score, and therefore will not be considered a valid next move in the path planning algorithm. Once the current objective point is reached, a new objective point is created at the end of the next row.

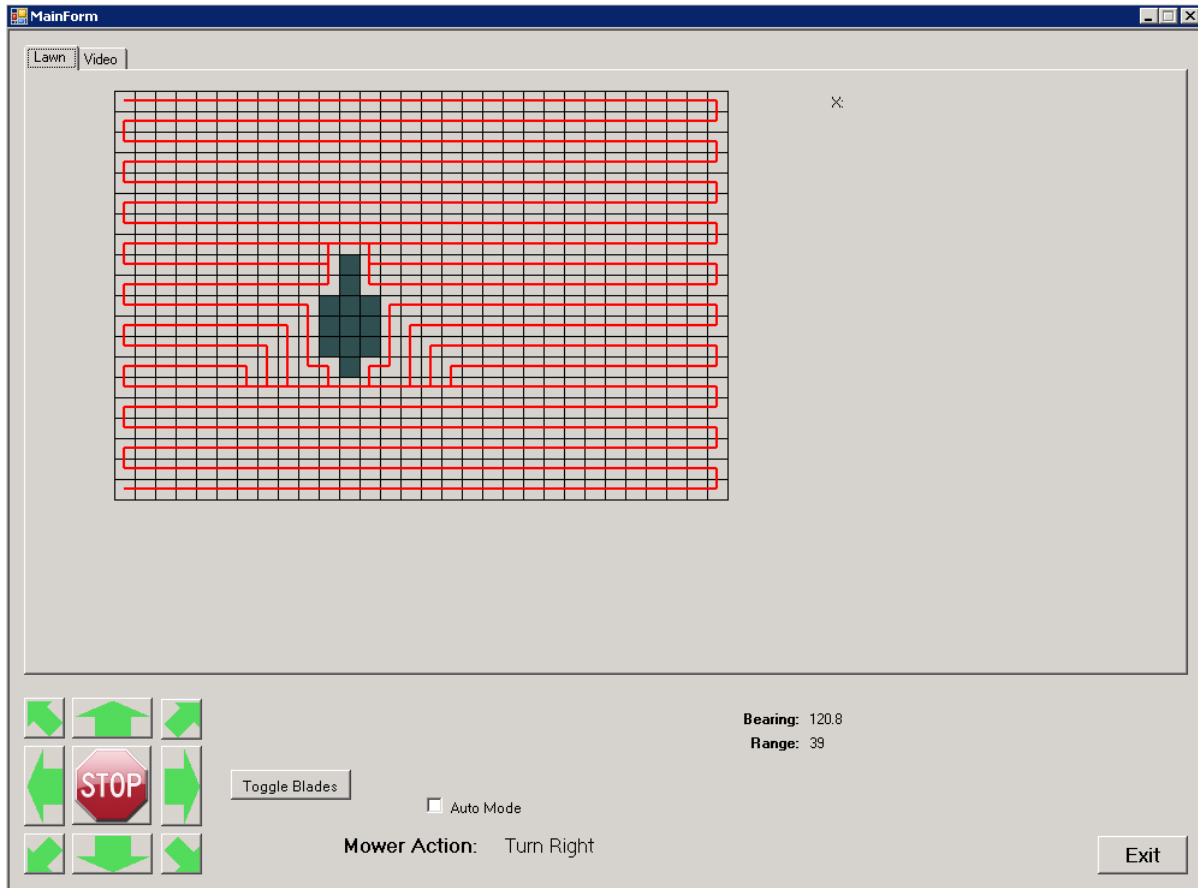


Figure 3.3.1 A screen shot of the GUI while debugging path planning. Path planning results from the A* algorithm using the Manhattan method to determine the heuristic term are shown. (Lawn Grid – Black, Mower Path – Red, Obstacle – Solid Square)

3.4 Kalman Filter

While the A* algorithm provides robust path plans, it relies on the system's sensors to accurately position the robot according to plan. Because the position sensors used on UC Robomow 2009 are less accurate than desired, a Kalman Filter is used to integrate the sensors and improve position accuracy using covariance matrices. Although the Kalman Filter is the driving force behind the lawnmower

when in the mow rows state, there is redundancy built into the design using the vision algorithm. When in the mow rows state, the vision algorithm runs behind the Kalman Filter and interrupts operation if a line is detected. Designing the program with the added redundancy of the vision algorithm prevents the lawnmower from leaving the mowing area due to poor Kalman Filter results or inaccurate sensor data.

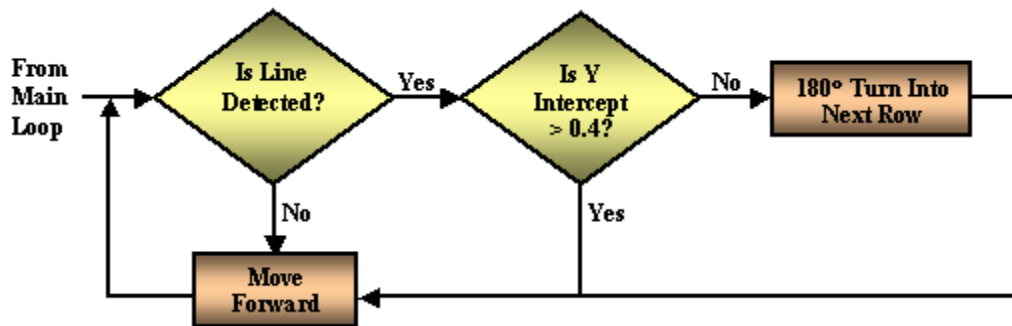


Figure 3.4.1 Logic diagram of the redundancy check on the Kalman Filter positioning, used to prevent the mower from heading outside of the mowing area while in the mow rows state

4 Safety System

4.1 Local Emergency Stop

The local emergency stop was implemented using a momentary push button switch in series between the battery and the RL850. When pressed, the switch cuts power to the RL850 shutting down all movement and blade activity until the button is released. When power is returned to the RL850, the custom control system will assume command of the RL850.

4.2 Remote Emergency Stop

The remote emergency stop was implemented using a radio frequency (RF) receiver and relay placed in series between the battery and the RL850. When the receiver gets a signal from the remote RF transmitter, the relay cuts power to the RL850 shutting down all movement and blade activity. When power is returned to the robot, the custom control system will assume command of the RL850.

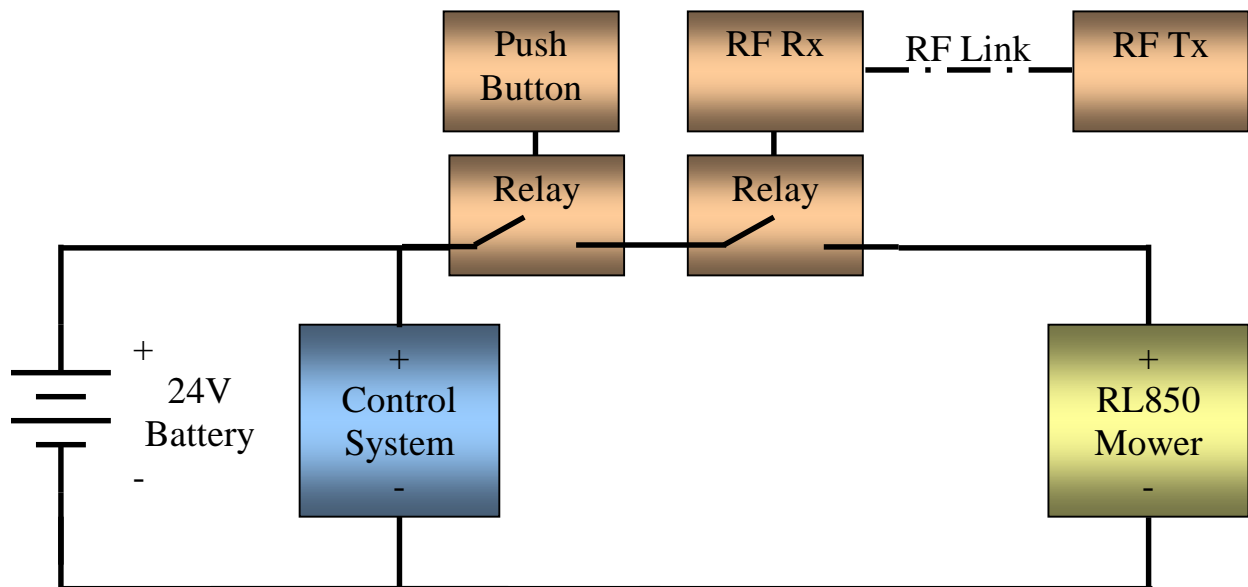


Figure 4.2.1 UC Robomow 2009 safety system diagram

5 System Integration

System integration requires the combination of the power/safety system, the control system, and the RL850 lawnmower. The RL850 includes an on board power system, which was used to pull power to the control system. The power system interfaces with the control system through an M4-ATX power supply, which then distributes the required voltages to each component of the control system. The control system interfaces with the RL850 via a parallel I/O port from the PIC32 to the RL850 controller.

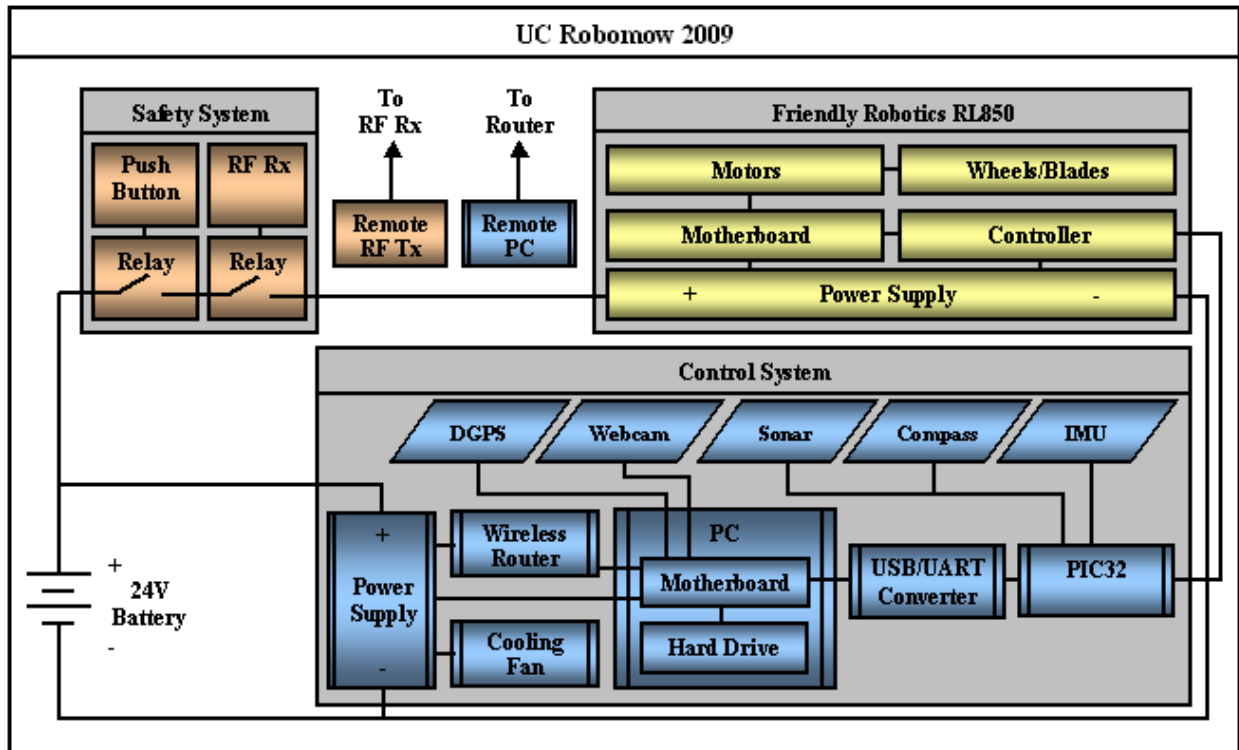


Figure 5.1 UC Robomow 2009 system integration diagram

6 System Specifications

6.1 Cost

The total cost, including both donated and purchased items, for UC Robomow 2009 was \$3302.60. The cost of donated items was \$2140.99 while the cost of purchased items was \$1161.61.

Summary of Costs			
Item Description	Quantity	Cost	Total
DONATED ITEMS			
Friendly Robotics RL850	1	\$1,999.00	\$1,999.00
Logitech QuickCam Pro	1	\$99.99	\$99.99
Linksys Wireless G Broadband Router	1	\$42.00	\$42.00
Total Cost of Donated Items			\$2,140.99
PURCHASED ITEMS			
Pactec CL-500 Plastic Electronics Enclosure	1	\$64.78	\$64.78
M4-ATX Power Supply	1	\$107.39	\$107.39
Intel Pentium E5200, 4GB SDRAM, 3GB HD	1	\$163.89	\$163.89
Zotac GeForce 7 Motherboard	1	\$54.57	\$54.57
Microchip PIC32 Starter Kit	1	\$63.74	\$63.74
Microchip PIC32 Development Board	1	\$87.18	\$87.18
San Jose Navigation FV-M8 GPS	1	\$153.29	\$153.29
Atomic IMU - 6DOF V2	1	\$188.64	\$188.64
IMU Programmer	1	\$20.00	\$20.00
Devantech R-117 Digital Compass	1	\$57.00	\$57.00
Devantech SRF10 Ranger	1	\$64.00	\$64.00
Devantech SRF10 Housing Unit	1	\$9.00	\$9.00
GWS Standard Servo	1	\$10.90	\$10.90
Remote Emergency Stop System	1	\$16.81	\$16.81
USB/Serial Assembly V2.0	1	\$29.00	\$29.00
USB/Serial TTL converter	1	\$36.00	\$36.00
Cooling Fan	1	\$19.02	\$19.02
Miscellaneous	1	\$16.40	\$16.40
Total Cost of Purchased Items			\$1,161.61
GRAND TOTALS			
Total Cost of Donated and Purchased Items			\$3,302.60

Figure 6.1.1 A summary of costs for UC Robomow 2009

6.2 Dimensions

The overall dimensions of UC Robomow 2009 are 37”x26”x 21.5”. The dimensions of the RL850 are 35”x26”x12.5” while the dimensions of the control system are 12”x12.5”x6” with a 6.5” camera mount extending off to one side.

6.3 Cutting Width

The cutting width of the lawnmower is 21”.

6.4 Mowing Speed

The mowing speed of the lawnmower is 1.8km/hr or 3.6km/hr depending on the user’s input.

6.5 Battery Usage

The SLA battery can operate for approximately 3 hours per 20-hour charge session.

7 Patrons

- The University of Cincinnati Robotics Laboratory
- General Electric Company
- Fosdick & Hilmer, Inc.
- Zion Temple First Pentecostal Church