# Lawn-O-Matic

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Our design aims to solve the problem of having to mow a lawn yourself. Using an ultrasonic positioning system, we will provide a solution by building an all electric autonomous lawn mower system. This system will provide a much more efficient and cheaper solution than the current autonomous mowers on the market.
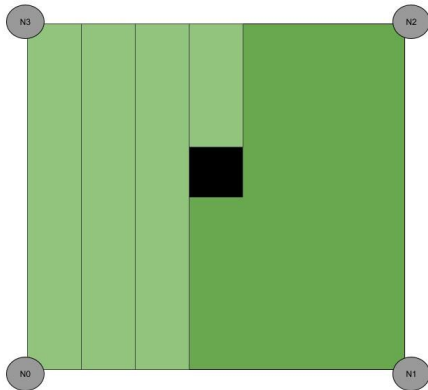
I. INTRODUCTION

THE problem that we aim to solve is the annoyance of having to mow your lawn manually. Nobody likes having to mow their lawn, and it can be expensive to hire someone to do it for you, around $1800/yr to be exact. According to the Chicago Tribune, the average American spends 70hrs/yr mowing their lawn [1], over 8 full work days in comparison. Our solution will allow people to instead focus on other matters like spending time with family or taking care of more important tasks around the house, leaving the lawn to our Lawn-O-Matic.

Imagine this instead, you go out to your lawn and place a "node" at each corner of your rectangular lawn. You then grab your lawn mower, place it at the starting node, and let it finish your lawn for you. You watch it mow in straight lines, back-and-forth across the lawn until it reaches the last, ending node. It has finished mowing the lawn and all you have left to do is some weed whacking.

Solutions to this issue have been attempted in the past, however no solution has implemented positioning to mimic the pattern that a human would mow their lawn. In our design, we aim to provide an autonomous mower to mow any lawn (within specifications) in a similar manner to how an individual may mow their lawn manually. In other words, our mower will be aware of its position and its surroundings, and will travel in a straight path across the lawn. Other automatic mower designs on the market operate at random, adjusting their headings upon meeting an obstruction. Inefficiently mowing a lawn in such a way may take hours! Our design attempts to deliver a solution that will efficiently mow a lawn within the time frame of a normal, non autonomous mow. We also aim for our design to be cheaper than other solutions the market has to offer. Automatic mowers on Amazon may range to as much as $2691 [2]. Our design will autonomously mow your lawn at an affordable price.

Our problem will affect individuals who may not be able to physically mow their lawn themselves for any reason, or may not have enough time during their workweek to mow. This project is unlike any other on the market today and will provide a cheap, reliable, and automated alternative for mowing lawns.

The ideal lawn that the Lawn-O-Matic will be mowing is one that is rectangular, completely level, and obstruction free. For a teenager who is looking to make money by mowing lawns, they will still be able to because this system is for flat and rectangular lawns. The Lawn-O-Matic could even mow one section of the lawn while the teen mows and trims in places where the Lawn-O-Matic cannot reach. The Lawn-O-Matic will be great for lawns that need consistent maintenance.

The specifications the lawn mower must adhere to are the following. The mower will be able to mow a lawn that is up to 20 by 20 feet (6 by 6 meters) and will have a margin of error of 6 inches (0.15 meters). This means that even if the mower is 6 inches off of its actual position, it will not miss any grass on the lawn. The specifications of the lawn size comes from the range of the ultrasonic sensors. The range of the ultrasonic transmitters and sensors is 650 feet. Therefore, the largest lawn the Lawn-O-Matic will be able to mow is 650 square feet. The accuracy of the system is determined through calculations based on the speed of sound and the environment in different degrees of temperature and levels of humidity. Using the speed of sound and the equation, $distance = speed \times time$, we were able to come up with projected distance errors if the measurements are off by a certain amount of time. Table 1 shows these values. Temperature and humidity also affect the speed of sound, but after doing some research we've concluded that these effects can be ignored. Even at 100% humidity, the speed of sound is only .35% faster than at 0% humidity, given conditions at room temperature and at sea level [3].

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Time Error (ms)	Distance Error (mm = inches)
.001	.34029 = 0.0134
.01	3.4029 = 0.134
.1	34.029 = 1.34
1	340.29 = 13.4
10	3402.9 = 134.0 = 11.1ft

Table 1: Sensor Accuracy

When completed, Lawn-O-Matic will be comparable in size to that of an average electric push lawn mower. The lawn mower will be 16"x16" with an aluminum base, weighing approximately 3 lbs [4]. The final product, consisting of an ultrasonic transmitter circuit, an Intel Edison, a LiPo battery for power, and a printed circuit board for the charging system will weigh about 7 lbs. The nodes on the corners, used for calculating the lawn mower's location on the lawn, will be very similar in size and shape to that of a normal lawn lamp decoration.

Specification	Value
Weight	7 lbs
Range	650 square feet
Battery Life	1 hour 10 minutes
Cost	~$500
Accuracy	6 inches

Table 2: Specification requirement for Lawn-O-Matic solution
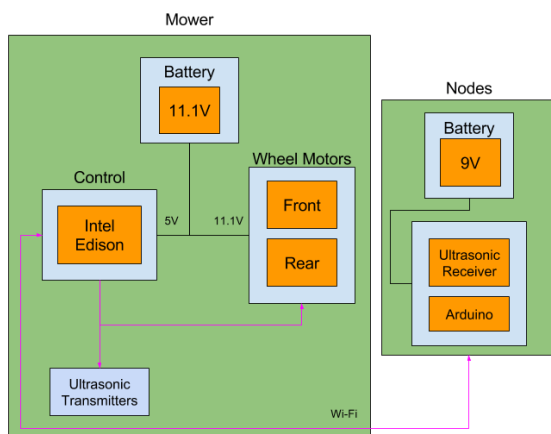
II.   DESIGN

A.   Overview

Fig. 1: Our block diagram that shows our design separated by nodes,

mower control/Intel Edison, and charging.

The design consists of two main blocks, as shown in figure 1, representing the lawn mower and a single node. On the lawn mower itself, there is a controlling computer, four ultrasonic transmitters, four motors and an 11.1V battery. An Intel Edison is used as the main controlling computer, maintaining the ultrasonic transmitters and wheel motors. Each node operates under the control of an Arduino microcontroller, effectively providing input into the ultrasonic positioning system. The Edison communicates with each Arduino via WiFi, the main medium used for communication throughout the design.

Each node consist of a single ultrasonic receiver, an Arduino, and a 9V battery for power. The Arduino receives information from the ultrasonic receiver and transmits it over WiFi to the Edison.

B.   Block 1: Nodes

Each of the four nodes is a system of three items that communicate with each other. They include an Arduino, ESP8266 WiFi controller, and the ultrasonic receiver. The datasheet for the WiFi controller [5] specifies an operating voltage of between 3.0-3.6V and uses 802.11 b/g/n protocols. The Arduino is used as the main controller to handle the WiFi and incoming ultrasound. We chose Arduinos because they are simple to use. We did not want to overcomplicate the four nodes. The input to this system is an ultrasonic signal and the output is a UDP datagram message which includes the node ID and the time of when the ultrasonic signal was received. The Arduino communicates with the WiFi module using a C++ library that implements serial communication over a BAUD rate of 9600bps (a requirement for the ESP8266). The library includes functions that connect the Arduino to a wireless network, create UDP and TCP connections, and also send and receive data. We decided to use UDP because it is faster and we want to constantly send data. The WiFi module first establishes a connection with the wireless network by the function, `wifi.init(SSID, PASSWORD)`. Once it establishes a connection it registers a UDP connection to the Intel Edison over a port and sends a message to the Edison. Each node does this over a different port. Once the Edison has received messages from all four Arduinos, it broadcasts a message, "Start", back to the Arduinos to tell it to start listening for ultrasonic signals. At this time, all nodes are listening for ultrasonic signals. When the Arduino reads the ultrasonic signal, it creates a timestamp and sends this timestamp to the Edison over the UDP connection and keeps doing this until the process is complete.

To test this block, two LEDs were included in the circuitry. A

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red LED turned on when the Arduino connected to the WiFi and then a yellow one turned on when it received the "Start" message. We knew it was working correctly because when each node was powered on, the red LEDs started turning on and then each of the four yellow LEDs turned on all at the same time, demonstrating that we had timing correctly implemented. To test the ultrasonic receivers, code was included in the firmware that would output, "Received", to the serial monitor when a signal was received. We moved the receiver away from the transmitter and the Arduino stopped outputting to the serial monitor.

To find the total power dissipated by each node, measurements were made in the lab using a multimeter. To find the power dissipated by the Arduino, the current at the input was measured to be about 105mA. The arduino is powered by a 9V battery so that gives about 945mW of power. Then for the ESP8266 WiFi module, the measured current at the input was found to be 70mA and the module is powered by 3.3V so that gives 231mW. In total, the power dissipated by the node is 1.176W. The capacity for a 9V battery is 500mAh and the battery's load current is 105mA. To approximate how many hours the battery will last, dividing the charge by the current gives 4 hours and 42 minutes.

Techniques used in this block came from mainly two classes: Software Intensive Engineering taught by Professor Irwin and Electronics taught by Professor Bardin. Software Intensive Engineering taught us how to use both UDP and TCP and how you can use it to communicate between a server and multiple clients. C++ was also another skill learned in Software Intensive Engineering which was required for this block. For the ultrasonic receiver circuit, skills obtained from Electronics were used. We needed a circuit to amplify the incoming ultrasonic signal into something that the Arduino could read digitally. The circuit included two general purpose operational amplifiers and a rectifying circuit at the end to digitize the signal. All of this was covered in Electronics.

C.   Block 2: Mower Control/Ultrasound Transmission

The controlling unit in this design will operate on an Intel Edison [6] microcomputer located on the lawn mower. The Edison controls four ultrasonic transmitter sensors, the mower motor, and the four wheel motors. In addition to controlling the devices on the mower, the Edison also operates as both a UDP server for the corner nodes, and a web server for user preferences.

The Intel Edison was chosen because of its minimal power usage, multicore architecture, and small size. Operating at less than a watt [7], the Edison makes for an ideal microprocessor for our lawn mower design. Battery power is

a very crucial specification. When compared to a Raspberry Pi model B (part number 756-8308), another possible microcomputer for this design, the Intel Edison will provide up to 25 more minutes of performance in our lawn mower design (derived in Equation 1 - time was calculated assuming the current through the ultrasonic transmitter circuit, roughly 2uA, is negligible, and each motor requires about 450mA at a low rotational speed). The Edison's lower power dissipation is made possible due to its lower current draw: 150mA [8] as oppose to the Raspberry Pi's 1.2A! (the 2012 model B) [9].

$$\frac{2.2Ah}{4(450mA)+150mA+1.8\mu A} - \frac{2.2Ah}{4(450mA)+1.2A+1.8\mu A}$$
$$= 0.394 \; hours \; \approx 25 \; minutes$$

Equation 1: Increase in battery life by using Intel Edison as opposed to the Raspberry Pi.

The dual-core Intel Atom processor within the Edison allows for multiple operations to run in parallel. Performing the UDP server and the mower control operations on separate cores will eliminate the possible unwanted delay due to context switching within the OS and hardware sharing within the processor. This effectively creates a *pseudo-realtime* microprocessor for the motor controls. It is important to note that the Intel Edison processor does not behave like that of a processor on a microcontroller, which executes instructions in *realtime*; thus the term *pseudo-realtime* is used.

Measuring to just about 35mm by 25mm in size [6], the Edison is a great choice for embedded systems where space is of an importance. This size will easily fit into our lawn mower chassis with room to insert our breadboard circuit for the ultrasonic transmission and our PCB design for the battery charger circuit. Other microcomputers, such as the Raspberry Pi (part number 756-8308) measuring to 85mm by 54mm [10], would be otherwise too large.

The software running on the Edison communicates with the onboard ultrasonic transmitter circuit via electrical signals generated as short pulses from the Edison's GPIO pin. The four ultrasonic transmitter sensors within the circuit provide for the location system by periodically transmitting ultrasound to a maximum distance of 650 feet. The sensors are separated equidistant from each other, each 90 degrees from its previous, to maximize the area transmitted. The Edison activates the 40kHz ultrasonic transmission by pulsing a single GPIO pin HIGH to 3.3V then LOW to 0v at a frequency of 50kHz for 14ms every 2s, as shown in Figure 2 below. The delay between each transmission is important to compensate for the many possible delays over WiFi. The transmission process occurs on a single thread on the Edison to allow continuous output to the GPIO pins.
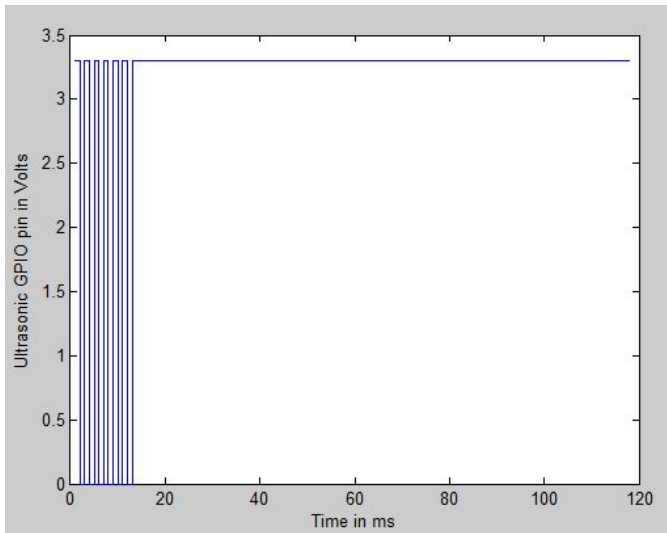
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Fig. 2: Time plot of 14ms GPIO pulse used to activate the ultrasonic transmitter sensors. The first 120ms is shown to clearly display the pulse.

The mower motor operates only within the boundaries of the user's yard. With help from the ultrasonic sensors to determine an accurate position, the Edison may activate or deactivate the mower by controlling the power flowing into the mower motor via a relay. However, due to limitations in UMass's safety rules on SDP, we have substituted an LED for the motor to indicate that the system has engaged it's mower. This simple alteration stems from the idea of safety within SDP, thus will prevent any possible harm caused by high spinning blades.

If the Edison calculations determine that the mower is within the boundaries of the lawn, it will indicate the mower is on by lighting the mower LED. This process will occur by signaling a GPIO pin on the Edison to HIGH, powering the LED with 3.3V. If in the case the calculations derive a location beyond the length or width of the yard, then the mower LED will turn off to indicate that the mower should not mow in a location other than the yard.

The Intel Edison also controls each wheel independently via four motors. Each wheel will be fixed, and thus not stirrable. To move the mower, the Edison must rotate one side of the wheels, for example the back left and front left wheels, faster than the opposing side, the back right and front right. In the event that the mower must turn around and travel in the opposite direction (such as in the case of reaching the length of the yard), then the mower will stop, rotate one side of the wheels forward while rotating the other side backwards to perform a 180 degree turn. The Edison will perform this process by writing to four individual electronic speed controllers via four GPIO pins, each controlling a single wheel.

The motors must be controlled by electronic speed controllers (ESCs) because of their type: D2830-1300 brushless motors. The ESCs operate as an ON/OFF switch for the motors, powered by the 11.1V battery. As an example, to rotate the motors at roughly half of their rated rotational speed, the ESCs will switch the power to the motors ON and OFF at a frequency large enough to provide an uninterrupted flow of current into the motors at a decreased rate. The Edison may increase or decrease the power to the motors, and thus their rotation speed, by sending an electrical pulse of variable width to its GPIO pins connected to the ECSs. This process is called pulse width modulation (PWM), and is exactly the method a Servo uses to adjust its arm angle. Measured pulse widths ranging from 1.7ms (and less) to 2.4ms sent to the ESCs map approximately to rotation speeds of 0rpm to 14,430rpm on our motors, respectively. 14,430rpm is the rotational speed limit of the brushless motors since they are rated for 1300KV (KV is a unit equal to rpms per volt).

The Intel Edison will have an active UDP server during the operation, listening specifically for packets from each of the four corner nodes. The server operates as the Edison's main source of input data needed to compute its calculations and determine its position. Running on its own thread, the server will actively listen for incoming packets to break apart and store locally for the Edison's local calculations. The UDP server is also a very important for synchronizing the clocks across each node and the Edison itself on startup. Timing is very critical for calculating the in-flight time of each ultrasonic pulse as they travel from the transmitter on the mower to the receiver on one of the four nodes. Thus, the Edison relies on the walltime from not only itself, but each of the Arduinos as nodes too.

Once started, the Edison creates a one time UDP server to synchronize the time between the nodes and itself. It first waits for each node to properly connect to WiFI by actively listening over UDP. Each node will send a packet over UDP once connected, notifying the Edison that such node is "online." Once the Edison received a packet from each node, it transmits a "start" packet to each node, notifying the nodes to create a local timestamp as a reference to the initialization of the system. Using the difference between any time after the start and the start itself, it will not matter if the clocks are set to the wrong time and date on any device. The Edison also records a timestamp a few milliseconds after to accommodate for the delay over WiFi. With this design, the Edison and Arduinos always refer to a timestamp relative to the start of the system.

The Edison will also provide the user with real time

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monitoring data hosted locally to the Edison over a web server. Users connected on the same network will have access to the Edison's output log files, as well as a percentage of lawn completion and an accurate position of the mower in the lawn. This product is intended to be used by a consumer, thus it is important that the user's experience is well itemized when bridging the gap between the software and hardware of the system.

D.   Block 3: Power
The 11.1V battery is a 20C, 2200mAh lithium poly-ion battery which will supply power to both the Intel Edison and the four wheel motors that move the mower. For convenience of the consumer, this battery will be charged at the same time as the 36V battery. A custom printed circuit board will be designed and fabricated to draw power from the mower battery to the 11.1V lithium poly-ion battery.
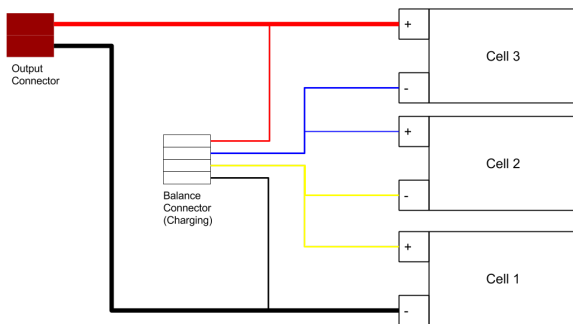

Fig. 3: Schematic of the lithium poly-ion battery.

The battery is charged via the four connections on the balance connector, as seen above in Figure 3. The 11.1V lithium poly-ion battery has an actual maximum voltage of 12.6V, with each cell having a maximum voltage of 4.2V when fully charged. The maximum current allowed into each cell during charging is 2.2A. For consumer convenience, there will be an LED on the circuit indicating when each cell of the battery is currently charging.

The charging circuit is designed to charge each cell up to 4.2V and no higher. When a cell is in its "charging" state a maximum current of 1.67A is allowed through said cell, 1.67A being about 75% of the maximum current of 2.2A. A simulation of the circuit in its "charging" phase can be seen in Figure 4. As the voltage of a cell increases and approaches 4.2V, the current going into said cell decreases until the voltage of the cell is, or nearly is, at 4.2V. At that point the current going through the cell will be practically zero making sure that the cell does not exceed its maximum voltage of 4.2V, damaging the battery. A simulation of the circuit in its "charge complete" stage can be seen in Figure 5.

The top left of the circuit in the schematics makes up the LED circuit, where D1 simulates the actual LED, that indicates when a cell is currently charging. As seen in Figure 4, when the cell is charging there is current going through D1 indicating it is lit and in Figure 5, when the cell is completely charged there is essentially no current going through it. The schematics do not show it due to program limitations, but all 3 cells will have an LED.

The most important components used in the circuit are the LM350T voltage regulator and the NP2N2222A transistor [9, 10]. The LM350T, parts U1, U2 and U3 in the schematic, in conjunction with resistors R2, R3, and R4, make up the voltage regulator of the circuit and ensures that the cells do not exceed their limit of 4.2V. The NPN2N2222A transistor, parts Q1, Q4, and Q6 in the schematic, in conjunction with R1 sets the current limit of 1.67A.

We ran many simulations making sure that the specs that we desired from the circuit in its "charging" and "charge complete" phases were correct. We plan for more extensive testing before PCB fabrication to avoid any possible issues and having to buy multiple PCBs.

Techniques used to build this block come from the courses Circuit Analysis I & II and Electronics I. These courses made us familiar with circuits, how to design, simulate, and test them using various electronic test instruments.
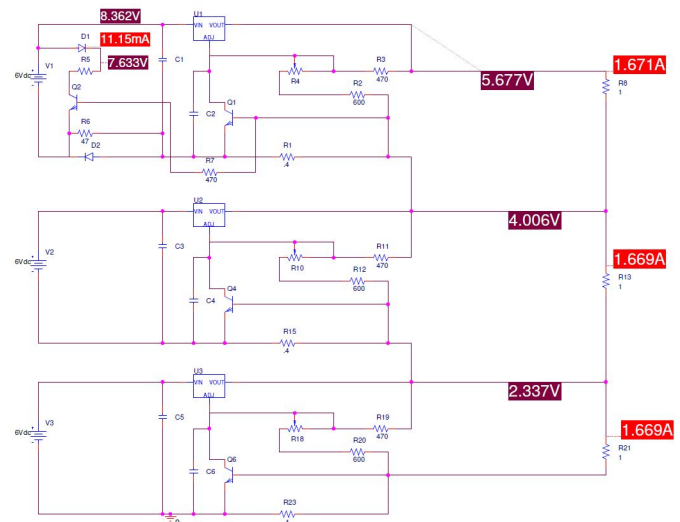

Fig. 4: Schematic of the circuit that will charge the lithium poly-ion battery. This is a simulation of the circuit when it is in its "charging" state.
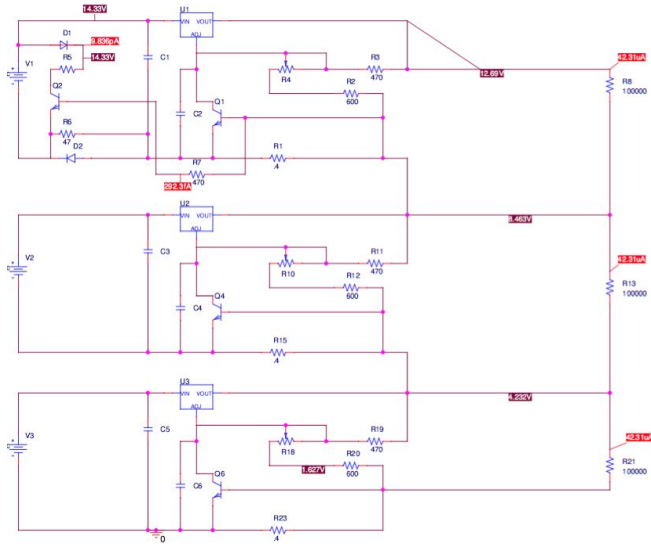
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Fig. 5: Schematic of the circuit that will charge the lithium poly-ion battery. This is a simulation of the circuit when it is in its "charge complete" state.

The current into the brushless motors was measured to ultimately determine the battery life of the LiPo battery. The current during a single motor's maximum rotational speed, mid rotational speed, and minimum rotational speed were measured to 790mA, 650mA, and 210mA, respectively. The motors will operate at a constant low speed while underway, consuming roughly 450mA each, and dissipating 20W of power between the four. At this speed, the mower will have a maximum battery life of 1 hour and 10 minutes, as derived below (150mA from the Intel Edison, 1.8uA from the ultrasonic transmitter circuit).

$$\frac{2.2Ah}{1.8A+150mA+1.8\mu A} = 1.128h$$

Equation 2: Battery life time

III.   PROJECT MANAGEMENT

MDR Deliverables	Status
Ultrasonic System	Completed
Edison Calculations	Completed
Communication via Wi-fi	Completed
Battery charging circuit	Completed
Location Detection System	Integrated, Inaccurate

Table 3: MDR Goals

As Table 3 states, all individual parts of our MDR deliverables were completed. The battery charging circuit for the 11.1V lithium battery was designed and simulated; all that is left for this is the PCB design and fabrication. The integration of the

location detection system was completed. The control system on the lawn mower is able to transmit ultrasonic beams as well as communicate with the nodes via Wi-fi. The location algorithm has been completed in the control system. The algorithm has been tested and confirmed to be accurate. The integration of the communication and location has been completed, although the results are inaccurate. There is more to be done to increase the accuracy of the complete location detection system to specification.

The team has been working well to communicate and complete integration of the systems as progress is made. Helping each other with their weaknesses is an important aspect of the teamwork.

The following expertise of each member of the team is as follows:

As a computer systems engineer, Jon's expertise is in hardware and software architecture within application specific designs. His previous experiences in software engineering at ISO New England and Brown Brothers Harriman have helped him gain advanced engineering insight at the professional level. Also, his previous tricopter, RC car, and automated plant watering system projects involved embedded system design, software architecture, and automation.

As a computer systems engineer, Jeremy's expertise is in embedded systems and software engineering. He interned as a software engineer for Allscripts Healthcare Solutions where he gained valuable experience in the software lifecycle and has been able to combine it with experience in school projects in hardware design.

As a computer systems engineer, Ahmet's expertise is in application development and software engineering. His previous experiences in school-related and personal projects have helped him gain valuable engineering experience.

As an electrical engineer, Robert's expertise is in circuitry. His experience in electronics and circuits shows up in the design and testing of the charging and ultrasonic sensor circuits. He has knowledge of components such as BJTs and MOSFETs to contribute to design. His ability to use and interpret measurements from electronic test instruments such as oscilloscopes, multimeters, and function generators contributes to debugging of circuits.

The plan for the future is illustrated in Figure 6. Our Gantt chart has the responsibilities from the beginning of the semester through CDR. The outstanding work illustrated by the Gantt chart is the PCB design, motor design, and UI
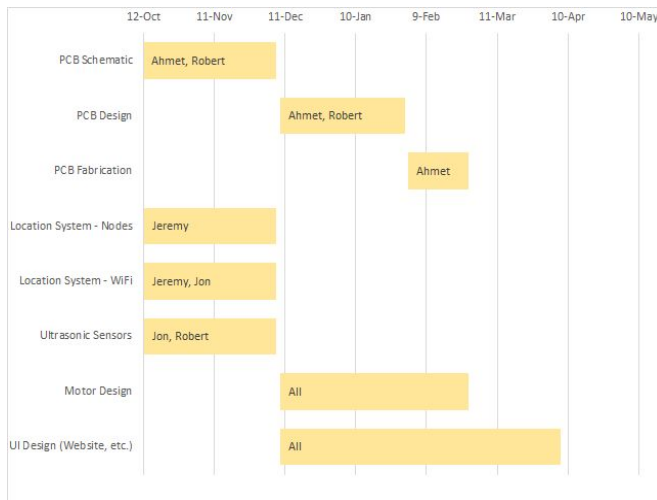
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design.

Fig. 6, Our Gantt chart demonstrating the work so far and the plan for the future.

IV.   CONCLUSION

The current state of our project consists of our MDR deliverables: the finished ultrasonic receiver nodes, the UDP communication over WiFi, the Intel Edison ultrasonic transmission circuitry and code, the Intel Edison position calculations, the synchronization of each CPU clock among the four corner nodes and the Edison, and a schematic and simulations of our charging circuit for the 11.1V lithium poly-ion battery. We achieved this by working diligently, meeting as a group at least two times a week and making sure everyone was keeping up with their part and helping each other when needed.   We will continue to work hard and aid each other as more difficulties with the system arise and together we will make sure our system meets our expectations.

Our plan for the future is to meet all our desired system requirements. A chassis will be designed to simulate a lawn mower with the control system integrated. The bugs with the location detection are to be solved and desired accuracy obtained. A printed circuit board consisting of the charging circuit is to be ordered and implemented in the mock mower. The system will be operational once these pieces are completed. The end goal is to provide a cheap and reliable method of mowing lawns with little to no physical labor. The main difficulties that we expect to face include the location system's increase in accuracy and the mower's increase in battery life. Both have proved challenging thus far, however we are striding for an affordable automatic lawn mower for consumer use. By the end of the spring semester, we hope to overcome these difficulties and produce our first functional prototype of Lawn-O-Matic.

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