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Self-Driving Retrofit Kit for Self-Propelled Lawn Mowers

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ABSTRACT

An in-depth look at the design process and research for a device that can fit onto currently used self-propelled zero-turn lawn mowers and can record and replay routes, to automate lawn mowing, a traditionally monotonous task. Discusses previous solutions and why this Retrofit Kit is needed, as well as how it differs from the previous solutions and patents. This report outlines the design of the Retrofit Kit, explaining why this specific design was chosen to solve this problem, as well as how the subsystems are divided and how they interact with one another. Thorough discussion of mechanical and software design, and a look at how the kit is designed with safety and other ethical concerns in mind. The planned budget and timeline for the team is included, showing how the team plans to utilize its resources to effectively create a prototype of the optimal design stated. There is also a look into how team members contributed and how each of the members can grow and learn from this design experience. This paper is an overhead look at the entire design process of the self driving Retrofit kit for self-propelled lawn mowers.
1. INTRODUCTION
1.1 Background

Lawn-mowing is a task that everybody can relate to as a homeowner. Countless hours have been dedicated to lawn mowing as it has evolved and adapted with technology as time has progressed. Lawn mowing is difficult for many reasons, because the lawn must be mowed well to look good. Mowing lawns can be hard on a person’s body, especially when doing it for 8 hours a day. If this didn’t have to be a person mowing the lawn, and it could be automated, this would be very beneficial to many homeowners and companies throughout the world.

Grasses account for nearly 26% of all plant life on Earth. With that in perspective it is clear that grass-maintenance is an important element to quality of life in society today. In order to achieve this improvement in quality of life, time and energy must be sacrificed by an individual to maintain the grass on their property, or furthermore for a client. In an attempt to preserve all of the time and energy that has been used for lawn-mowing, an automated solution for this task must be presented.

It is known that expensive equipment must be used to mow the lawn efficiently. In an attempt to improve currently existing lawn-mowing equipment, a retrofit kit that attaches to these currently used lawn mowers is the best solution. The act of implementing a kit onto an existing mower eliminates the need to buy new equipment, ultimately saving the client money. The retrofit kit is also eliminating the potential effects of waste accumulation by disposing and replacing dated equipment rather than simply upgrading the existing machines.

1.2 Purpose of the Project

The purpose of the RetroFit Kit is to automate the task of lawn mowing. Automation of any traditional task can prove to be controversial. The RetroFit Kit for automated zero-turn lawn mowers is intended to enhance the work-life of commercial users, and the home-life of residential users. As a result, homeowners would be spared hours of their free time, and commercialized businesses would be able to relieve some of the strain placed on their employees. Conclusively, the RetroFit Kit provides a means of saving money for its consumers through upgrading existing lawn equipment rather than replacing it.

1.3 Previous Work Done by Others

*Navigation Method and System for Autonomous Machines with Markers Defining the Working Area (see [2])*

A method for automatically operating a lawn mower or other unmanned machines was created and tested via F Robotics Acquisitions Ltd. in Pardesiya, Israel. The overall consensus within creating this automated system involves the installation of physical boundaries that are detectable through the use of proximity sensors. The input to the system comes from these proximity sensors which then is fed to a processing unit. A navigation unit is implemented into the system to establish coordinates of the robot relative to an arbitrary origin position, a direction
finder, and memory to store the coordinate values generated by the aforementioned processing unit. The method includes the steps of causing the robot to start from an origin of known coordinates within the working area, to then continuously determine the coordinates through analysis of the sensor inputs. Then finally, implementing corrective actions through comparison of the actual coordinates of each boundary to the calculated coordinates of the robot.

**Local positioning system for automated lawn mowers (see [3])**

A method for establishing a local positioning system on an automated lawn mower has been previously established by Nelson Russell of Cane Hill Arizona. Within this method, two fixed sonic transmitters as well as an omni directional audio receptor mounted on a lawn mower. The sonic transmitters send out an auditory pulse which is then received by a condenser microphone and the time it takes to receive the pulses is measured via a counter. The counter data which is in time, is converted into distances which are the x and y coordinates of the sonic transmitters relative to the mower. Based upon the coordinates received by the microcontroller aboard the lawn mower, decisive outputs in the form of movement allow the mower to effectively navigate the working area and complete its task. With the location information accumulated from the sonic transmitters, the onboard computer can receive and store this location data and program the path the mower is taking, to then allow the mower to traverse a previously recorded path.

### 1.3.1 Existing Products

Many major manufacturers have created automated lawn mowers. There are no kits or devices created to make a previously manually operated lawn mower automated. The automated lawn mowers that are available on the consumer markets currently fall under the category of robotic lawn mowers. The robotic lawn mowers do not recycle much of anything other than plastic so for anyone purchasing an automatic lawn mower is making their previously owned equipment useless and wasteful.

The Husqvarna AUTOMOWER 435X AWD [1] is a robotic mower that can mow a lawn up to 0.9 acres in area using GPS navigation patented technology. The Husqvarna AUTOMOWER is a device that mows the lawn itself while having a charging station it parks itself on. The device has connectivity to an app on the user’s cell phone to make any adjustments with the robot. Some of the features included in the app include adjusting the height of the cut, a weekly timer you can adjust to fit your schedule, and theft protection using GPS. The Husqvarna mower detects the weather outside to know if the lawn is fit to be mowed.

Gardena also makes a robotic mower capable of mowing up to 2500 square meters [2]. The Gardena mower also has a smart app to connect on your smartphone. The Gardena uses a perimeter wire and the length of your wire determines how much area the robotic mower will work in. For the area within the perimeter wire, the Gardena mower uses collision sensors to ensure that the robotic lawnmower is not stopped by garden obstacles. The Gardena also uses a charging station to automatically charge itself similar to the Husqvarna series of automatic
mowers. Gardena created the mower to be weatherproof so rain or shine the mower can get the job done.

1.3.2 Patent Search Results

United States Patent 6,984,952 est. January 10, 2006 - Navigation method and system for autonomous machines with markers defining the working area [3]:
The technologies that may be built upon from this patent are the physical elements such as the proximity sensors included in the robot, and the physical boundaries such as electrical wire run through the ground forming a perimeter around the working area.

United States Patent 8,027,761 est. September 27, 2011 - Local positioning system for automated lawn mowers [4]:
This patented technology uses sonic transmitters to emit auditory pulses and measures the time to receive those pulses back in order to establish an x-y coordinate system for the lawn mower. The use of sonar technologies in the retrofit kit has not yet been ruled out, so this patent is included.

1.4 Brief Overview of the Project

Lawn mowing is one of the few tasks that nearly everyone throughout the world can relate to in the sense of how physically and mentally demanding it tends to be, especially when done at a large commercial scale. Countless hours have been dedicated to lawn mowing as it has evolved and adapted with technology as time has progressed. In an attempt to preserve the resources such as time, energy, and money that go into lawn mowing, making the task automated is necessary. Automated lawn mower’s already exist, however, they currently are not effective at industrial levels and are highly expensive. This is where the “retrofit kit for self-propelled, zero turn lawn mowers” enters the picture.

A “retrofit kit” designed to fit common commercial zero turn lawn mowers would effectively solve many of the labor issues associated with the act of lawn mowing. Creating new automated technologies and then implementing them into their respective industry comes with many ethical concerns. The goal of automating the process of lawn mowing is not intended to replace workers and landscaping companies, but rather accommodate them in a highly effective manner. The possible implementation of the retrofit kit into the landscaping industry creates the opportunity for workers to perform less physically demanding tasks and potentially act as an overseer to the automated mower.

The possibilities for the capabilities of lawn mowers operating under the retrofit kit’s control are endless. The automated system has to be able to establish a fundamental sense of space, and basic level understanding of its surrounding environment. A working boundary would be physically installed into a working area prior to use of the automated system unless the boundaries were hard-coded and modified for each working environment or yard. GPS technologies have been used to solve these discussed concepts previously through patented methods. Logical thinking and decision making would have to be computed by the automated system in real-time while simultaneously completing its task. This is all made possible through the capabilities of the microcontroller and the inputted computer programs.
The difference between the realm of this project versus previously completed work is that the retrofit kit has a real opportunity to be a universally adaptable technology. It does not require the user to purchase new equipment, but rather it upgrades their existing equipment and is extremely user friendly. There are not many mechanical aspects to controlling the lawn mower, it is mainly done through the programming of a microcontroller, however, this microcontroller must be shielded from the elements through the housing feature. This will be done effectively, and the aesthetic of the retrofit kit device will seamlessly transition into the design of commercial zero turn lawn mowers.

2 PROJECT DESIGN

This section will describe ideas for the design of the retrofit kit and the optimal design that will be implemented through a prototype.

Alternative Design #1 (Record and Replay)

The first alternative design is programming based. This design will focus on how the Retrofit Kit will create a route and store it. The basic idea of this design is that the Retrofit Kit will be installed on a lawn mower, and once it is installed, the user will mow the lawn with it installed. While the user mows the lawn, it will record the necessary data and then when the user is done recording, it will save all of the data it has collected. Once it has all of this data, it will have the ability to replay this route exactly.

The first part of the program is recording the route. This could be done several different ways, but the way in this design will be using servo motors or some other type of motor that can record the distance and speed of the arms of the mower being moved. This can be recorded very easily by recording the value sent back by the motor into storage.

The Retrofit Kit is using a Raspberry Pi microcontroller, so the way to have permanent storage on it is through the SD card installed on the microcontroller. This allows data files to be accessed even if the Raspberry Pi is turned off, and allows for multiple routes to be stored. If the data is written to a file called “route_x”, and the x changes for the different route numbers, then different routes can be created and accessed depending on user input.

Alternative Design #2 (Sensor Based Route)

This design approach looks to control the Retrofit Kit with complete sensor control, unlike the approach before where it logged the route through user input. The design would focus on making the sensors log as much data as possible. The physical design of the system could be very similar to the design above, but for this design it will be a bit different. This design would rely on a touch screen to make choices. This design could be smaller and allow for deeper error messages to be shown.

The touch screen would have a menu for options. The first option would be to record a new route. When clicked, it would show a dot on the screen to represent the mower. When the “Start recording” button is pushed on the screen, the lawn mower would start moving in a straight line, and it would map out the edge of the lawn. Since this is a mapping procedure, it would move slowly, making sure to try to map the edge of the lawn as carefully as possible.
The front and sides would have many infrared sensors to tell distance. This would allow the mower while recording to detect imminent objects. The sensors would start recording where objects are and these would show up as red outlines on the screen. The screen would show this mapping with north at the top, because the Retrofit Kit will have a built compass to know its direction at all times.

As it is moving, it will log the GPS data every time it has to turn to avoid an object. This allows for vectors to start to be formed, where an angle from north can be the direction of the vector, and the magnitude of the vector is the amount of GPS distance moved. This allows for the map on screen to show the outline it created, and from there it can be decided if any points need to be adjusted.

To make sure the on screen map correctly shows all of the obstacles during the recording process, an algorithm would be made to correctly read the different sensor datas and use them to convert into distance with GPS data. This allows for points to be placed on a map, and obstacles can be shown with these points that would form an outline of the object.

Because so much data is being logged about mapping the edge of the lawn, all of this data has to be stored efficiently. This would be stored differently than the first design, because this design would store obstacles and the map differently. Since it has so many sensors, it can rely on the sensors to know where it is within the given boundaries.

The first file to be stored for a route will be the edge map. This will have the coordinates of the edge, so that the boundaries of the route are set. Once the boundaries are set, the lawn mower can just fill in the boundaries, going from one side to another and turning around to fill the boundary in.

The second file associated with a route will be all known obstacles. This will include the ones from the edge of the lawn, but also ones that are in the middle of the lawn as well. This will be written to only during the record phase, and will be used to cross reference any obstacles that are found during a playback time. The obstacles will be recorded by the sensors and transformed into a format that is usable with the GPS data, so that as the lawn mower moves along the yard, any obstacles seen by the sensors will trigger the program to make sure that's an obstacle seen before. Given the relative position of the obstacle and the obstacles listed in this document, it can identify when a new obstacle is found, and stop the lawn mower accordingly.

The Retrofit Kit will create these two files the first time the lawn is recorded, and store them in a similar format to the files from the first design, with “boundary_x” and “obstacles_x” being the names of the files. These can be overwritten by a new record session. The playback of routes would be pretty simple. There would be a button on the homescreen of the touchscreen called “Mow Lawn”. Once clicked it would lead to a menu that showed previews of the routes, and these routes could be custom named as well. Even though the files for the routes would be associated with numbers, these routes would just have an on screen name associated. The user would choose a route, and then hit the “Mow Lawn” push button on the screen.
This would lead the mower recognizing its position and starting its route. Since there is GPS data on this one, it would not need to start in the exact same spot every time. It can recognize its position in the lawn, and make decisions from there. As long as the mower is recognized to be within the boundaries, the mower will begin moving and mowing. If the GPS data shows that the mower is outside of the boundaries for that file, then it will cancel the route and give an error on screen.

Unexpected obstacles like people or animals would be very easy to detect with this design, because it has extra sensors, and the obstacles are listed in even more detail. Instead of just knowing that there is an obstacle in front of it, it will know after recording the lawn, the general size of the obstacle will be known, and how it can go around the obstacle. With this knowledge, the lawn mower can intelligently decide how to move around that obstacle, and then continue back on the route. Even though it never learned from a user what to do with an obstacle it can still react in a positive way.

Because of the increased amount of sensors, there are more cables coming out of the kit itself. This would increase the amount of set up needed, because more sensors would need to be properly attached, and the wires would most likely need to be routed so that they are not just dangling. This could be a modular design, with the different sensors having their own screw terminals so that they could be replaced if broken, or if more are needed then they could be added with ease. This also allows for different mowers to use the same kit, just with a different outfit of sensors and controls. Since most of the controls of steering and turning the lawn mower off in this design are mechanical, but controlled with the Raspberry Pi, this kit would be powerful enough to work with any lawn mower, and certain parts would need to be designed to fit the lawn mower specifically.

With the design being focused on the sensors, there would be a lot more code for this design. This could use machine learning to create optimal routes, along with using machine learning for moving around obstacles and creating maps for the user to preview. Another function that could be added with this design because of the touch screen is the user friendliness. With more data pulled in from the internet, the lawn could be shown with a satellite image, and users could say what lawn mower they are using so that the width of the blades is correct so they always have the optimal mowing done.

A possible option for this design could be a camera added to it. Having an algorithm that could detect what kind of objects are in front of the lawn mower would allow for very smart routes that could tell where a sidewalk is and where trees and bushes are. This would allow for close mowing next to trees and other known obstacles, because more information would be known. Because of the camera too, other user-friendly features could be used. Having a way to connect to it, like Bluetooth, users could watch the live feed, or get notifications when the mower is stopped by an unexpected obstacle.

Overall, this design is a lot more programming and sensor heavy than the first design. Having to program a screen, watching sensors, and deciding how to fill in the boundaries is more
intense on the microcontroller. This would be a very marketable design, because of its user-friendliness.

**Alternative Design #3 (Mechanically Manipulated System)**

The third alternative design of the Retrofit Kit for Automated Lawn Mower system is a mechanical-control based system that utilizes a Raspberry Pi microcontroller for basic automation capabilities. Through the employment of mechanical lever-arms and motors, the steering, gas, and brakes of the lawn mower can be controlled. This is possible utilizing feedback gathered from proximity sensors within the system that gather data about the surroundings which is then fed back to the Raspberry Pi for control. The user interface for this alternative design includes an automate button. The only user input needed to activate the Retrofit Kit would be the act of manually starting the lawn mower, and pressing the automate button that is on the outside of the Retrofit Kit.

This design of the Retrofit Kit will involve an experienced technician for installation. The kit will provide all necessary parts for the kit to be installed but drilling and extensive tools may be required. The kit must be different to fit each type of lawn mower's control mechanisms. For example if the mower is controlled using a lever system typical in a riding zero turn lawn mower, the device will control the levers from the junction between the lever and the mower floor. If the mower has a hand controlled lever similar to the ones used on riding zero turn lawn mowers, the control mechanism will be installed on the handlebars. For the blade control and other control modules, the kit will include mechanisms designed to either push/pull the button or slide a lever forwards and backwards on the control panel to have full control of the mower's capabilities.

Commercial-grade zero turn lawn mowers are all powered with a 12V power supply. This battery can be easily accessed and used to power a Raspberry Pi that employs proximity sensors, which can read and transcribe the depth-perception data of the working machine. Through the processing of the gathered proximity data, the Raspberry Pi’s embedded programming would allow for simple decision making when the lawn mower would be in use, and perhaps when encountering an obstacle or boundary of some form. These decisions would include whether or not to toggle the blade on, the path of motion, toggle headlights on or off, and speed of travel of the working lawn mower.

**2.1 Optimal Design**

The optimal design that has been decided upon throughout the group is a combination of all three alternative designs. After further research involving several different zero-turn lawn mowers, it is apparent that controlling a lawn mower purely electrically is too complex; mechanical mechanisms will have to work in parallel with electronic mechanisms for sufficient automation. The combination of the three alternative designs includes programmable and repeatable routes that are created by the user, sensor technology for the mower to have life-like reaction to surrounding interactions, and physical mechanisms controlled by electronic motors connected to the microcontroller.
2.1.1 Objective

The design of the retrofit kit includes the software to the physical manipulators that control the movement. The overall view of the system can be broken up into several parts. The first is the Raspberry Pi, which will have several programs on it to control steering, record routes from the users, and be able to replay them. This will also be in charge of managing the data from the sensors, which is another part of the system. The sensors will be a GPS sensor, 5 infrared distance sensors, whiskers to detect objects in front of the lawn mower, and a sensor to detect cardinal direction. The electrical design of this system is mostly designed around these sensors, but also has some other parts to it as well.

The electrical system will be powered by the 12V battery on the lawn mower. This will be converted to 5V for the Raspberry Pi, but the 12V will also be used for the motors. The motors will control one of the physical systems, which is pushing and pulling the steering arms. This will control direction and speed, which is necessary for the automation of the lawn mower. The motors will be turned on and off by the Raspberry Pi, but powered by the 12V battery with a dual h-bridge. These two motors will control a rack and pinion that will move forward and backwards to move the steering arms.

The other part of the retrofit kit that was designed was suitable housing for the microcontroller so that it would be safe from water and other types of damage that could harm the system over time. This was designed to have protected seals for all of the wires that are leaving the housing to control different parts.

The final part of the design was the software that controls all of the data coming in from the sensors, and tells the motors how to control the lawn mower. This is very important because the system could not be automatic without this control, and the program must be built to be efficient, so that data can be processed quickly so that the lawn mower is safe.

A large part of this design is based around safety. Certain parts have been designed to kill the mower when unexpected obstacles are found, to protect people and animals that stray in front of the lawn mower, as well as objects that could hurt the lawn mower. Every part of this design considered safety as the number one priority, and every step of the program checks for safety when possible.

Overall, this design is a large process, with many subsystems and processes. The implementation of these ideas found below will take place piece by piece, so that each part works effectively before working on the next part. The electrical and software control will be done side by side, and as mechanical parts are manufactured or bought, the software will be developed alongside that as well. Each part of this system has to be created with the other in mind, because if they do not go all together, then the system will likely fail. In this next section, the more specific details of the subunits are explained, with the physical, electrical, and software control all explained thoroughly.

2.1.2 Subunits

Within the design of the RetroFit Kit, there are subsystems at work that collectively allow for the automation of many commercial zero-turn lawn mowers. The RetroFit Kit utilizes both
mechanical and electrical technologies, each with their own subcomponents that complete the art of automating a zero-turn lawn mower. Through the set of many subunits, or subsystems within the RetroFit Kit, sensory data is able to be gathered and processed to allow for decision making capabilities of the zero-turn lawn mower itself.

2.1.2.1 Physical Manipulators

In order to create a RetroFit Kit for automating a zero-turn lawn mower, mechanical elements must work with electrical elements to complete the overall design and task at hand. When considering the automation of a zero-turn lawn mower, physical manipulators will be required to create certain movement capabilities. This is required in many areas across the lawn-mower’s mechanical-anatomy for proper control of the system. Essentially, these physical manipulator’s are replacing the mechanical aspects of lawn mowing that a user is currently responsible for operating.

Figure 1: Rough Sketch of Throttle, Brake, and Steering Manipulator

(a.) Movement Control

Although the current specific measurements and mechanisms are not entirely decided upon, a rough basis for controlling the handle-bar controlled steering mechanism has been theorized. The steering control also happens to be the control for both the gas and the brake system on zero-turn mowers, so conquering this aspect of control with a physical element is highly prioritized.

In most cases, a zero turn lawn mower is operated using a hydraulic lever system. There is a left lever and a right lever. Each lever is responsible for the speed of its coordinating rear wheel. The levers are set in the neutral position when the mower is not moving at all. As the
right lever is pushed forward, the right rear wheel rotates forward at the corresponding speed to how far the lever is pushed. As the left lever is pushed forward, the left rear wheel rotates forward at the corresponding speed to how far the lever is pushed. Both levers have the ability to be pulled backwards past the neutral position, giving the mower reversing capabilities. Pulling one lever backwards and pushing the other lever forwards allows the mowers to complete a 360 degree turn without moving positions at all hence why they are called zero turn lawn mowers.

The manipulators incorporated in the retrofit kit for the Toro Z400 mower’s steering levers will use existing threaded holes in the bottom of the lever shown inside the white rectangles in figure 2. This allows the retrofit kit to be easily attached to the levers. The mechanism bolted to the bottom of the lever will have the ability to push and pull the lever it’s full range of motion. The pushing and pulling will be done by a DC motor connected to a gear system to maximize torque while requiring minimal electrical power. The DC motors and gearing system will be mounted on the frame rails inside the pink rectangles shown in figure 2. The steering mechanisms will have to be different shapes and sizes to fit each different model of mower on the market, so this optimal design is created for the Toro Z-Master Z400 lawn mower.

Figure 2: Under the seat of a Toro Z-Master Z400 lawn mower

The physical manipulator to take control of the steering, throttle, and braking lever on the Toro Z-Master Z400 mower is shown in figure 3. The smaller gear will be driven by a DC motor controlled by the programmed microcontroller. That smaller gear is connected to a larger gear which also has a rack and pinion connected to it. The gear ratio will be calculated to minimize the torque required by the motor to move the rack and pinion which will also conserve the
amount of power required from the motor. This mechanism will be mounted by drilling and bolting a mounting system to the mower by an experienced technician.

![Figure 3: Optimal Steering Mechanism Design](image)

(b.) Control Panel Control

The control panel interface of every zero-turn lawn mower is going to be physically different, however, many of the mechanisms that control these control panel settings are universal. The implementation of all these features into one location makes it easy for the operator to modify their equipment to fit the operating environment and conditions. Although many of these control panels are going to vary in appearance between makes and models of zero-turn lawn mowers, the mechanisms that are actually used to control these features on the panel are going to be similar in terms of mechanical properties.

As mentioned previously within this section, both mechanical and electrical components will have to collectively work together to automate a zero-turn lawn mower. Many of the features within the control panel of zero-turn lawn mowers are electronically controlled. This is going to be the headlights, the hour-meter, and the ignition switch that you will typically find on a control panel. The mechanical features which are to be controlled physically through the implementation of manipulators, include the throttle, choke, and blade toggle.

In order to gather more foundational knowledge of the control panel operating system on commercial zero-turn lawn mowers, two industry-leading models were inspected. Depicted in figure 4 below are the control panel interfaces on both the Toro Z-Master Z400 and John Deere Z-trak Z970R commercial zero turn lawn mowers.
The control panel’s for both zero-turn lawn mower models include all of the same features. Although the features differ visually from model to model, their functionality remains the same. Boxed in navy, are the engine-choke pulleys. These pulleys are driven by a linkage assembly that is located in the rear of the mower near the carburetor. Control over the choke is essential as it is required to be configured upon mower startup. Next on the diagram, we have the hour-meter boxed in red. This system is pretty self-explanatory, and runs off an electrical connection to the 12 volt battery within the mower. The hour-meter provides the ability to track how many hours of operation the lawn mower has endured, and is useful for noting important run-time thresholds for maintenance. This feature will not have to be controlled as it is programmed to run when the mower has been started up.

Boxed in yellow are the ignition switches of each respective mower. These switches are electrically controlled and powered by the 12 volt battery power supply. Control over this feature is required to properly start the mower through the turning of the engine. This will be done electrically, not mechanically. Following that, in green, we have the throttle assemblies for each mower. This feature allows the mower to increase the level of speed the mower is traveling, and is controlled through a linkage also located near the carburetor of the mower. This linkage is identical to that of the linkage which controls the choke. When mowing the lawn, speed of travel is an asset to efficiency, therefore the throttle is an important mechanism to have command over. Lastly, in purple, we have the blade toggle pulley for each commercial mower. This control is purely electrical and will have to be controlled as such. Control over this feature is important as it is what allows for the grass to be cut, which is the ultimate goal when lawn mowing.
Furthering the validity of these claims, the control panel unit of the Toro Z-Master Z400 was disassembled to reveal the controlling mechanisms behind the panel features.

**Figure 5: Toro Z-Master Z400 Control Panel Driving Mechanisms**

The physical manipulation of the control panel begins with the analysis of the driving mechanisms that were discussed previously in this section. Currently, only two of the four control panel features are driven mechanically, the throttle and the engine choke. This is done through the utilization of a linkage mechanism that is attached to the carburetor to allow for the engine to intake more oxygen. It opens up the airway when the choke is pulled on the panel interface. The same thing goes for the throttle as it opens a valve for more gas to power the mower when pushed into the open position. It decreases the amount of gas the engine receives when pulled to the closed position. In order to successfully automate these features, physical manipulators will have to be implemented within the control panel interface that are powered through an electrical signal. When the physical manipulation unit receives the electrical signal, it will push or pull these features to a degree that varies upon what is electrically inputted.

Depicted below in figure 6, we have the first iteration of the control panel mechanical control hub.
In this conceptualized design of the control panel mechanism control hub, the hub piece would be a small box that is mounted onto the existing panel. The box would have a slot built into it with a lever control arm that can physically push and pull the throttle and choke accordingly with the power of a DC motor. The control arm will be spliced into two branches and each will have a manipulator fitted to its respective control-piece dimensions. This is just one of the potential ways to solve the problem, and seems to be the most practical method.

2.1.2.2 Electric System

The main objective of the electrical system is to maintain control over all of the different parts, with the brain of this control being a Raspberry Pi. Raspberry Pi’s are very skilled at taking complex programs, having SD cards for storage, and have digital I/O pins that can help it control many systems. The Raspberry Pi is the brain of the circuit, and almost everything in the circuit connects to the Raspberry Pi in some way.

The circuit must control the motors that move the arms, must receive data from infrared sensors, as well as a GPS sensor too. This will be powered by the battery of the mower, since that recharges with the alternator of the mower. The circuit needs to have a power switch, so that excess power is not drawn from the battery.

Seen below is the schematic for the retrofit kit:
This schematic shows the complete picture of all of the pieces together, but to explain the design choices, it will be broken up into 3 major subsystems, which are power, sensors, and motors. These subsystems all depend on the Raspberry Pi controlling them, and the Raspberry Pi was chosen for a variety of reasons. Raspberry Pi and Arduino are both excellent platforms to easily program and connect systems to, but the Raspberry Pi stood out for several reasons. The first being that a Raspberry Pi can handle a lot more information than the Arduino platform. Another is the ease of being able to program in Python, instead of C, and that is explained in the software section below.

The biggest reason that an Arduino was considered was because it has analog pins to read values between 0V and 5V, up to 10-bit clarity. The Raspberry Pi only has digital pins, and that limits the sensors a bit, unless an analog to digital converter was used. That seemed to be a valid option for the Pi, but research made it seem like a difficult option, and would need extensive coding. The Raspberry Pi and the Arduino both have I2C on the boards, and that can be used instead of analog pins. This is an exceptional part of the Raspberry Pi because most of the sensors that will be attached to this can be attached with I2C, and it only takes 2 pins on the Raspberry Pi. With that in mind, the Raspberry Pi was the clear choice.
(a.) Power

This circuit is powered by the battery on the lawn mower, because the lawn mower recharges the battery with its alternator. The Raspberry Pi needs 5V to be powered, and that is through the USB-C port. The way this is handled is through a DC-DC converter, which will need to have an output range of 4.9V to 5.1V. This would allow the Raspberry Pi to be powered, and it can draw up to 3A of current. So this DC-DC converter would need at least to be rated for 15W, but 20W to be safe. It would take the 12V from the battery and transfer it.

The 12V will be needed in other parts of the circuit though. The 12V will power the 2 motors that control the lever arms of the lawn mower. Since the lever arms take a lot of torque to be moved, the motors will need to be strong, which usually means higher voltage and current. These motors could not be powered by the I/O pins on the Raspberry Pi, because those have a voltage of 3.3V and cannot supply more than 16mA current.

The sensors will be powered with the 5V from the DC-DC converter. This ensures that the Raspberry Pi is not powering all of the different parts of this system which protects the Raspberry Pi from overheating or hurting itself.

(b.) Sensors

There are two types of sensors in this system. The first is a GPS sensor and the second are several infrared distance sensors. The GPS sensor is going to be a Raspberry Pi hat from Adafruit. This was chosen because of its reliability, and easy programming. Adafruit has a tutorial on how to use this specific sensor, and has data showing how accurate it can be. It has -165 dBm sensitivity, 10 Hz updates, and 99 search channels.

The GPS sensor is going to be used for location data. It can also be used for time data, but there is not a need for that in this retrofit kit. The GPS sensor gets its power from a battery on the device, and can communicate with the Raspberry Pi by connecting to its hardware UART. This limits its output from the TX/RX pins but this project will not need these pins anywhere else.

The other sensors are infrared sensors. There will be 5 infrared sensors that will be placed on several parts of the mower. There will be one on the front right, front center, front left, back right, and back left. This allows for the most amount of safety coverage. Since the Raspberry Pi is limited to only digital pins, and no analog ones, the only way to read a range of values for all 5 sensors is if the sensors output with I2C. This would allow each sensor to have its own channel to connect with the Raspberry Pi.

The sensors may not come with configurable I2C addresses, so an I2C multiplexor is needed, so that each of the infrared sensors can have its own address. A multiplexor designed for this purpose would allow for easy address management. This would allow for easy design of the
electrical and software of the retrofit kit. Seen below is the multiplexor and the sensors together.

![Figure 8: Close up of the multiplexor and the infrared sensors](image)

This is just a representation of course, the multiplexor is going to be a bit different for simplicity. Here is an example of what it could be like:
The multiplexor seen above gives each of the I2C devices everything it needs, Vcc, ground, a data connection and a clock connection. This then connects back to the Raspberry Pi’s I2C pins (pins 3 and 5) and also gains its power from the DC-DC converter and ground. The multiplexor with all of the sensors fills all of the sensor needs while using the minimum amount of pins on the Raspberry Pi.

(c.) Motors

There are going to be two DC motors that will be moving the arms back and forth to control the steering of the machine. These two motors will need a torque of at least 50oz-in, and this means that the motor will need a good amount of power to turn and move the steering arms. Seen below is the motors within the schematic:

Figure 10: Close up of the motor part of the schematic
The motors have a dual H-Bridge motor driver connected to them to drive them. This is because the Raspberry Pi by itself cannot power the motors. The simplest solution is to use an H-bridge for each motor so that they can use the battery for power, but use the Raspberry Pi for control. The Raspberry Pi controls the IN pins and the Enable pins for each H-Bridge. The IN pins tell the OUT pins if they should be high or low. The high or low values for the IN pins are determined by the SENSE pins. The high values for motors are determined by the voltage at the Vss pin.

This allows for the battery to power the motors, and the Raspberry Pi to control the motors. This can also be controlled by Pulse Width Modulation (PWM), which means the speed of the motor can be chosen too. With the signal only being on 50% of the time, it would slow the motor.

The only requirements for the H-Bridge is that it can have 3.3V sense voltage, and the power limit is high enough. Once the motors are decided, the power requirements of the motor will decide the power requirements of the dual H-Bridge.

The electrical system will power the whole system, and give all of the control to the Raspberry Pi. The only other part of this system is the on/off switch, which just allows power to the Raspberry Pi, and the buttons for the control of routes. These will all be connected to digital pins, and will not be very complex. They will be built with pull-down resistors, so that the power draw is reduced while the system is going.

The electrical system was designed with a lot of consideration of the programming and the software that is going to run this. They have to be considered when designing each other, and the programming will support all of the electrical design.

2.1.2.3 Software

The programs will all be written in Python due to it being object-oriented programming, and its plentiful supply of example programs and packages for use online. Python will be easy to use on the Raspberry Pi, because it has a Python programming environment built into its OS (Raspbian). Python can also allow routes for more complex programming for future steps of this project, and is very readable.

For the software there are two main tasks the program has to perform. The first is recording a route, and the second is replaying stored routes. Within both of these, required safety features will be added. These programs will use some of the same resources, because recording a route will save a file that can be accessed by the replay program. This subsystem will have 4 major parts to it, the route files, movement controls, the record program, and the replay program.

(a.) Route Files

The files the routes are based on are going to be the driving force for both of the programs, so it must be explained first. The route files will be stored in their own respective folders within the Raspberry Pi's storage. The reason for their own folders is for uniformity in the code. When opening the files needed for recording or replaying, the only part that will need to be changed is the name of the folder. These folders will have the titles labeled as
“route_package_x”, where x is the number of the route. The number of the route will be given in the record and replay programs by user input.

Inside each folder will be the files named “gps_data” and “sensor_data”. These two files will all be written to when creating or rewriting a route, with data being added to each in a JSON format so it can be easily read in Python. Each file will have several different types of information stored, so having it in JSON format will allow for repeatable types of information to be found as it reads through the files.

In the first file called “gps_data”, the data will be the chronological data read by the GPS sensor, with the longitude and latitude data being the two main things being kept. The other part to be added is the cardinal direction data, which shows the direction the lawn mower is facing. JSON files are created with a list of dictionaries, and the major keys for these dictionaries will be “long_data”, “lat_data”, and “compass”. The data associated with “long_data” and “lat_data” will be a list with 2 elements. The first will be the degrees for longitude/latitude, and the second is the minutes (following +/- conventions to help with math) An example of what the dictionary would look like can be seen below:

```json
{"long_data": [-74, 00.4168], "lat_data": [40,0.4168], "compass": 270}
```

This data will help to locate the mower’s position and direction. This can be used to make sure the lawn mower is going in the right direction and mowing over the correct areas of the lawn. Having the compass direction helps to know if the lawn mower should be turning or not, as well as making sure the lawn mower is moving correctly.

The other file, called “sensor_data”, is collecting all of the data read by the sensors. Since there are 5 sensors, these will be stored in a JSON file separate from the GPS data to allow for faster reads of the data from the GPS data file. These will be very similar, with the 5 keys being used in the dictionaries being “front_right”, “front_center”, “front_left”, “back_left”, and “back_right”.

(b.) Movement Controls

This part of the software is to have easy to access controls for the mower. This program will be a module for the replay program. It will have definitions for several types of movement, like forward, reverse, adjust_direction, zero_turn_right, and zero_turn_left. Two other definitions to be added to this are also the definitions for controlling the two steering arms (one definition for each arm), so that these can be called as the other definitions need them, making the code more readable.

(c.) Record Program

This part of the software records data during the initial mow, and then stores the data in the correct route package. It takes in data from all of the sensors, and formats them correctly to be added to the JSON file. Seen in figure 11, the flow chart for the logic of this program is seen.
This program will only be started if the record button is pushed. Once the record button has been pushed, it has 2 options. If it is pushed again, it cancels the operation. If a value for a route is chosen instead, the record program will begin, using that number to open up the folder “route_package_x” with the corresponding number. From there the program will begin a loop that reads all of the sensor values, which includes the GPS and infrared sensor data, and then they will be placed into Python dictionaries, with the keys and values being the ones found above for the route files. They will then be added to those route files, and then the process will be restarted.

This is a relatively simple loop, but it is crucial to the operation of the retrofit kit because it needs to create data for the route to be replayed. One of the important pieces of this is that the user is creating this route by mowing the lawn the way they would, so that the lawn is mowed in the most effective way possible. This design was chosen over another design where the sensors and GPS would let the retrofit kit drive automatically and create its own route, but this could have a lot of safety concerns, as well as the program would have to be a lot bigger and complicated to ensure that the lawn was fully mowed, and that the route was most optimal.
Obstacles like trees or bushes don’t require the mower to do a full 90 degree or 180 degree turn away from the object, but just needs the mower to go around it. If this obstacle is in the middle of the yard, sometimes the lawn mower needs to go to the right and then other times needs to go to the left of the obstacle.

Since these can be hard things to ensure with just infrared sensors and a GPS sensor, having the user create the route makes the whole system easier to create, and better protects the system from known obstacles that need to be avoided, and allows for recognition of obstacles that are not supposed to be there.

Once the record button is pushed again and held for more than 3 seconds, the files are closed and saved, and the record program ends. The system then returns to a state where it is waiting for its next command, which could be another recording or playback of a route.

(d.) Replay Program

This program takes a route given by the user and starts to replay it. When a user clicks and holds a numbered button, it will start the replay program with that route number. Seen below is figure 12, which shows the flow of the program.

![Flow chart for the replay program](image)

The flow chart shows that the button is pushed, but also has a cancel button. If the record button is pushed after the x-value button, it cancels the replay, and it also checks for the files to be written to. If they are not written to, then cancel the replay. Another thing that can cancel the program and all movement is if the GPS coordinates at the beginning of the file are very wrong. The threshold for this safety feature is to be determined, but it should check that the mower is in
the right lawn. Usually the mower should start in the same area (within 10 feet at least), so the GPS data shouldn’t have too much error percentage with the current GPS data.

Once the files are checked and the first coordinates look good, this program turns to a loop for the rest of it. This program is just like a 3D-printer program, where if the print starts, and it gets stopped, the print has to restart entirely. Once the replay starts, it will read through the two files constantly until there is no more data to be read. The steps in the loop are:

1. Read a line of the two files
2. Check the GPS data and compass direction
3. Check the sensor data (kill the mower if necessary)
4. Calculate how the mower should be steered and send the command
5. Check for end of file

The first step is reading a line of the files. Since they are being stored as JSON files, this will be a single dictionary from each file. To make it more readable, there may be a function called to read the next lines and then store all of the necessary info in easier to use variables.

Then the program will check all of the data. It will check the GPS data and make sure that the mower is in the right spot. This involves using the previous information and the current reading of the GPS sensor and comparing them to make sure that everything is correct. As long as it is in a close enough range of everything, the sensor data can be checked. If there is an error here, that will be used for the steering algorithm. If the error is too big, then the retrofit kit will shut down for safety reasons.

The safety feature of all of the sensors is very important. Every time the loop is run, the sensor data must be read. All 5 of the sensors will be compared to their recorded values to make sure there is not a significant difference in what is being read. If any one of these 5 infrared sensors read something a lot closer than it is supposed to, the replay program will initiate a kill switch that turns off the mower. In seated mowers this could be simulating someone coming off of the seat, which kills the mower as a built-in safety function.

Having the sensors read every time will make sure any unexpected obstacles are seen and then the retrofit kit is safer to use. The biggest part is to make sure that any known obstacles are not used to kill the program. That’s why the recorded sensor data is so important, and if the GPS/cardinal direction data is off as well, then some type of algorithm to match the current sensor data with the right recorded sensor data is important.

Once the sensor data is checked, and the mower is confirmed to be good to continue on, the new values for steering must be made. A decision must be made to go forward (faster or slower), to turn slightly (with an indication of how far), or to do a zero turn to turn 180 degrees (also an indication for right or left). This is why the definitions above exist, so that this is more readable. Since these commands will be repeated over and over, it makes sense to only write these once in another module.

The last thing the loop will do is look for the exit condition. If the file runs out of data, the mower moves the arms to the stopped position and does the kill switch. This is the end of the loop and the program. Another optional feature is to have a kill button on the device that can also
exit the loop, or a remote with a kill button to stop it from far away. Either way, if the file runs out of GPS data, that means the lawn mower has done the whole route and should stop. Overall, the software for this will need to be developed in parts, just like how this is separated. Each part of the program will need to be created separately, so that each part can be tested and debugged. This is a significant piece of the retrofit kit, and without proper programming the automatic functions of the device will not function, rendering the device unmarketable. The Raspberry Pi will also have to be programmed to start a program that commands the record and replay scripts to be played. This will be done with startup programs, and will be a simple script that just looks for the input buttons and is a continuous loop as long as there is power.

2.1.2.4 Housing Features

Within the realm of outdoor work, the exposure to rain and other elements are always a possibility. To ensure the reliability of the RetroFit Kit in harsh working conditions, all electronics, and working units such as the physical manipulator systems, will all have to be shielded from these elements in some fashion. Although each of the intricacies for each protection hub design will differ, their function remains the same. The purpose behind these hubs is purely their function, so a minimalistic approach to design appearance is taken. It is crucial to ensure the implementation of these protective elements will not disrupt any working elements within the lawn mower’s natural system.

The material choices for all of the housing features of the RetroFit Kit will more than likely be a hard plastic that is properly sealed to avoid any fluid entering the working devices. There will have to be a high vibrational dampening material that the housing features are attached onto the mower with. This is done to resist any plastic deformation or mechanical failure due to vibrations from the running lawn mower in its potentially harsh working environment. Ideally, these structural elements are to be 3D printed to allow for limitless customization. The structural integrity of the materials used will have to be effective in both warm and cold climates. Right now polyurethane seems to be a promising material to fulfill these needs.

There are going to be numerous methods to test the structural integrity and functional efficiency of these housing features. Simply attaching the housing features to the mower without powering the devices inside, vibrational effects can be analyzed and further utilized to improve design intricacies. To be able to assess the impacts from weather elements the RetroFit Kit will be operating in, the lawn mower with housing features will have to be run for some specified period of time, and then returned to storage to assess. Artificially, it is even possible to simulate certain environmental conditions so the housing features could be under direct impact from these simulated conditions and further analyzed for effectiveness. Physically, the housing features will be rapidly prototyped and multiple will be available to discard after testing exposure to external forces. There will be failure testing, impact testing, and various other structural tests for documentation. Depicted below is the first iteration for the RetroFit Kit’s housing elements. This one specifically refers to the control panel unit.
2.2 Prototype

2.2.1 Physical Components

The prototype design of the retrofit kit includes eight operational components and their respective mounts. The raspberry pi computer is mounted in place of the seat on the lawn mower to signify that the computer is driving the lawn mower and human interaction is no longer required. There are four ultrasonic sensors mounted on the lawn mower. Three of the ultrasonic sensors are mounted toward the front of the lawn mower. One sensor is mounted directly in the front of the mower facing directly in front. The other two are mounted on the front corners of the mower at a 45 degree angle to account for any objects approaching the sides of the mower. The final ultrasonic sensor is mounted directly on the back of the mower to allow for reversing or overall maneuverability with surrounding data. There is also a limit switch sensor mounted directly in the front of the lawn mower. This limit switch or “whisker sensor” is used for any small object that is small enough for the ultrasonic sensors to recognize grass or bumps in the lawn that are too large for the blades to go over. A good example of this would be a large stick that is embedded into the lawn from being in the same location over winter. The ultrasonic sensors may not detect a small lump in the grass. The whisker sensor will hover the grass and if it is dislocated in any direction the lawn mower will shut off immediately.

The prototype created for the Toro Z Master Z400 zero turn lawn mower was 3D printed using PET-G material in a fused deposition model. PET-G filament has many reasons to be used for the Retrofit Kit application. The PET-G filament has a higher thermal resistance, and is UV-resistant; which will be required for outdoor application. The PET-G also has a density over 20 times the density of PLA filament. The impact force is the only statistic that PLA is favored due to its ductility upon impact. We concluded that a higher impact force was not in our realm of necessity for this application as the weather and climate will cause more strain on this device than any impact.

**Retrofit Kit Housing**
Designing the housing unit for the retrofit kit was a wonderful challenge in the sense that both form and function had to intertwine particularly to create the overall structure. It was noted that this is an outdoor application, and the microcontroller is to be protected and shielded from any foreseen weather elements. The base was first modeled as a hexagon with four slotted walls. The idea that these slotted walls could provide a means for ventilation of the working microcontroller, while also being shielded from elements, is where “Mighty Mesh” from Rayner Covering Systems came into use. This mesh material is woven to achieve a 98% shade value; only 2% of light is able to pass through it. This mesh was later cut to size, and epoxied into the slotted walls to provide a means of screening the working electronics inside. The floor of this central housing unit is slightly elevated, so if by chance any moisture were to accumulate inside, the working electronics would be elevated above where that minor amount of water would stagnate on the floor.

The next functional feature that was desired on this central housing unit was a hinge. This hinge would make the retrofit very user-friendly as they are able to easily swing the top of the housing unit open to expose the inner electronic components as needed. This was done using a personal design secret. Lastly, the final two elements to the housing unit include its mounting brackets that straddle either side of the base symmetrically, and the ½” cutout for corrugated conduit for running wires to the working components of the lawn mower.
2.2.2 Program Capabilities

The other part of the prototype is a rover that was used to test the programming and the software. This was designed to allow the Raspberry Pi to safely execute all of the code to test for any bugs. This is seen below, in several pictures.
There is a GPS HAT that gives data on the position, which communicates with the serial interface.

Another part of the design is the magnetometer, which allows the rover and retrofit kit to know which way the machine is facing. This is seen below.
The recording and replaying of routes is controlled by python programs, with details below, but one python script runs the full program. Recording a route can be started by pressing the red button, and is indicated by the red LED.

The record program measures the GPS data and puts them into a JSON file, which can be read and used for replaying the route later. There are several built-in functions for debugging and making the program as streamlined and easy to read as possible.

The replay function can be accessed with the blue button, which will trigger the device to start replaying the route. One of the innovative features of this prototype was the idea that it could be applied to many different mowers, and the functions to control the actual movement of the device. Each lawn mower is different, and it is very easy to change how each program chooses to control the different moving pieces.

The replay function was also built around safety, and many sensors can be built into it to protect people, animals, and the environment from danger.

The Raspberry Pi was used to program all of this, and a lot of software was developed to make sure that the program was safe, and then efficient. Safety was always first for the programming, which is why the program may seem a bit slow. Several things that could be improved upon in the next version of this is the prototype. It could be more accurate, incorporate more sensors, and move the rover faster. Right now, the rover only moves forward for one second at a time. Since it is so small, it does not cover much ground at a time.

On the lawn mower, since actuators are used instead of servo motors, the electrical and programming prototype had to be different. The electrical system is controlled by H-bridges and PWM instead of PWM servo control. This allows for forwards and backwards movement of the actuators.
The programming also had to be adaptive for this. The mechanical movement of the actuators means that the movement of the lawn mower is not exactly the same as the movement of the actuators. The actuators could be moving backwards and the lawnmower would be losing forward velocity, but that could mean slowing down in the forward direction or gaining speed in the backwards direction. This is important to note because the speed, direction, and overall movement of the lawnmower must be controlled by the position of the actuators, and not the speed of the actuators. This is a different concept than the servo motors, whose speed was controlled.

The code does reflect this though. The prototype was able to move the mower and measure how far the actuators were moving based on data taken from the data sheets. This is not exact though, and more effort and research could be placed into this specific part. The code is overall predicting a lot of things now, and it will always need to predict parts, but the algorithms needed to predict the path, and how the lawn mower is controlled needs to advance significantly for this to be a realized product.

3 REALISTIC CONSTRAINTS
3.1 Engineering Standards
The RetroFit Kit is founded on the basis of Engineering Standards. The number one engineering standard this project is remembering is safety. This project has the intention of making lawn mowing a 100% safe activity to have performed all around society on a daily basis. Everyone around a machine with the retrofit kit attached to it will be completely safe and no one needs to develop serious injuries riding around on lawn mowers for eight hours every day.

Engineering standards of productivity and efficiency are a very large motivation for this project. Lawn maintenance companies and golf courses would have much less labor hours to pay for mowing and more work could get done per hour.

3.2 Economic Constraints
There are numerous constraints involved with the production of the retrofit kit for self propelled lawnmowers. The first and foremost constraint is budget. As of right now, the project is funded with $1,000 granted by Northern Illinois University. The project has been applied for the Student Engagement Fund and the READ grant through Northern Illinois University. The lawn mowers the retrofit kit will be operating are worth well over $1,000 by themselves, so an available lawn mower for testing will be required. The mechanical components that will be required to undergo extensive design, prototyping, and creation are going to be made out of hard metal like steel. Hard metals require expensive machining to work properly. These components are going to be very expensive.

Another portion of the budget will be put towards how to make the retrofit kit as durable as possible with hard plastic casing around all of the sensors and computer box. The manipulators attached to the mower to control the functions of the mower will also need to be protected from the elements that the mower faces. These plastic casings will also cost a significant amount to have molded or 3D printed.
3.3 Environmental Constraints

A very large benefit of the retrofit kit is that it will not create more emissions to be produced than what is already used to mow lawns. The production and manufacturing of the retrofit kit may produce some carbon gasses for the CNC machines to cut or mold the metal parts for the mechanism linkages and gears, but most manufacturers have created zero emissions factories and that is a priority for this project.

3.4 Sustainability Constraints

The sustainability of the retrofit kit is very important to the objective of the product. The retrofit kit must be as tough as the mower itself. The device will have the responsibility of driving a lawn mower for many hours a day for years. To do this properly the device will have to endure all of the stress and strain that a lawn mower will produce and endure during all of the hours of operation. The goal is for there to be no extra maintenance for the kit to be attached to the mower. A lawnmower produces a lot of vibration that will test the sustainability of the kit.

A large factor in the sustainability of the retrofit kit is the mounting of the kit. To combat the vibration produced by the lawn mower the retrofit kit’s computer housing will be mounted using rubber or spring brackets. For a mechanical component that is responsible for moving the steering lever of the lawn mower, the only way for that mechanism to function properly it will have to be drilled and bolted to a structural part of the lawn mower. For the kit to be durable enough to handle the same wear and tear as the lawn mower, hard shell casings will be used over all electronic and mechanical components of the kit.

3.5 Manufacturability Constraints

Manufacturability is a very large constraint for the retrofit kit. As the kit has to take over the mechanical systems of each individual lawn mower on the market, there is little potential for one design to fit every lawn mower available. However, there is potential for one mechanism to fit multiple lawn mowers of the same manufacturer or structure. The retrofit kit will consist mostly of universal parts that will attach to every mower on the market. The sensors, microcontroller, and all the wiring harness will be the same for every lawn mower. The only part of the retrofit kit that cannot be universal for every mower is the mechanism controlled by the microcontroller that will be physically taking over the mower’s capabilities that previously a human would be interacting with.

The retrofit kit being required to have different mechanisms to attach to different lawn mowers is a large constraint because each mechanism will have to undergo all the designing, prototyping, manufacturing, safety and reliability testing as the others. Every different manufacturer has their own type of engineering behind the structure of their machines. The retrofit kit will have to take all of those designs into consideration to create the appropriate mounting options.

The more universal the manipulators are, the easier the manufacturing will be. This is because if every mower requires a different manipulator mechanism, then it becomes difficult to manufacture that many different manipulators to fit every mower. It is much easier to repeatedly
recreate the same part assembly than to create smaller amounts of many different part assemblies.

3.6 Ethical Considerations and Constraints

Within the realm of automation, there are a number of ethical constraints pressing the matter. It has always been feared that artificial intelligence would one day be able to functionally replace humans. During the industrial revolution there was a significant amount of job loss due to the automation of certain industries. This stems from the fact that robotics and machinery can replace humans in monotonous tasks, and not have to be compensated. The contribution of the RetroFit Kit to the lawn care industry could have similar impacts and consequently lead to contributing to the ever-growing financial gap between the rich and poor.

3.7 Health and Safety Constraints

Within the current design of the RetroFit Kit there are multiple sensory units employed through the system to gather environmental data. These sensors must be properly tested and calibrated prior to use to prevent any systematic failures. The other factors at risk for health and safety within the RetroFit Kit are the mechanical features that manipulate certain aspects of the mower. These mechanical elements will all have to be tested for effectiveness and safety prior to their implementation.

3.8 Societal Constraints

Technology seems to be advancing at a rate more rapidly than ever. This can be either praised or deemed a threat varying upon several factors. When trying to gather support around any sort of revolutionary automated device, there is a societal boundary that can act as a barrier to innovation. Potentially stemming from worker’s rights and other basic humane principles, there is some pushback against projects such as the RetroFit Kit.

The RetroFit Kit has the potential to revolutionize an entire industry, orders of magnitude that have not been felt in recent years. This comes with heavy benefits towards larger companies as they could potentially replace their workers with low-cost machinery. This is not the intent of the project and will be avoided at all costs. The RetroFit Kit comes with many good intentions, in the sense that it should be a physical relief for workers rather than a pressing threat, however, it is simply not possible to align with everyone’s individual viewpoint. The degree to which the RetroFit Kit will be accepted will vary with each and every individual.

3.9 Political Constraints

The RetroFit Kit’s progressive nature could lead to conflict with any reserved points of view. The effect of the adaptation to a semi-automated industry could prove to cross boundaries of worker’s rights in the eyes of some. This will come with natural pushback, as with any revolutionary innovation.

4 SAFETY ISSUES

Automated technologies have the potential for misuse. This is no different from any device on the market, however, programmed into the RetroFit Kit are safety shut-off features that are implemented to avoid catastrophic situations. The lawn mowers are equipped already with emergency shut off electronic systems. Some of these systems have electronic elements that
would no longer be necessary, like the seat pressure sensor emergency shut off. If the RetroFit Kit is driving the mower, there would be no use to have a seat on the mower so the electronic seat pressure switch can be used to be pressed under certain conditions that the programming assigns. There would also be no operation of the emergency brake switch that turns the lawn mower off if the emergency brake is not held on while the mower is not being moved. The RetroFit Kit is constantly in control of the lawn mower’s throttle and braking system so the emergency brake will never be on physically. This leaves the issue of not having an available emergency brake that physically stops the wheels from moving instead of relying on the RetroFit Kit to be able to keep the mower still if it has things going on around it.

The mechanical and electrical elements will all have to pass safety standards and testing protocols. These tests will be held throughout the entire engineering process with this device. Safety is the number one importance for the creation of this device. These tests will include object identification tests to make sure nothing but lawn is touched by the mower. The Raspberry Pi will have multiple paths of programming created for the mower to know how to react to different objects that it comes in counter with. When the mower comes in contact with a tree the action would be to slow down, and make a circle around the base of the tree to mow the grass around it. In a different instance, if the mower were to come in contact with a golfer on the golf course then it would shut off immediately to let the golfing continue in peace until no one is around again. The programming will be sophisticated enough to react smarter, faster, more efficient, and most importantly safer.

The same thing goes for the sensory units employed throughout the system as they are the “eyes” to the system and need to be working properly to assure safety. The sensors will have to relay an extensive amount of information about the surrounding area so the microcontroller can give the mechanisms enough time to react properly to anything it may encounter.

Another safety feature is that routes will not start unless it is started in the correct area. This protects the lawn mower from starting a route in the wrong area, and prevents a lot of misuse. The ultimate goal is to make sure that the route is always replayed the exact same as the first time it was recorded.

One of the goals of the program will be to have a control built in that makes sure the lawn mower is stopped, so that if it just needs to stop and not be fully turned off. There will be features to fully turn it off and for it to just stop to control the safety features even more. Extensive testing will be done to make sure all of these features work.

5 IMPACT OF ENGINEERING SOLUTIONS

The RetroFit Kit has the potential to be adopted across the entire commercial lawn care industry. This can lead to many positive lifestyle benefits pertaining to time management and user safety. As with any revolutionary project, a seamless transition into the lawn care industry with minor disruptions is ideal. To properly satisfy this requirement, the RetroFit Kit is intended to be a user-asset and its purpose is not to displace any current lawn care employees. There will always be the pending requirement for user interaction with the RetroFit Kit device as lawn mowers get transported from lot to lot. There may be minor imperfections with the work done by
the RetroFit Kit, and a user will be required to complete any final touch up details to the worksite.

The RetroFit Kit’s design parameters will have to be modified based upon mower make and model. In order to properly install this device the lawn mowing equipment would have to be taken to a certified technician. There are many intricacies within the mechanical elements that will have to be altered per mower make and model. Driving mechanisms may require more power based upon mower make and model. The RetroFit Kit central hub will be universal throughout all lawn mower models.

This product will affect society because it could reshape lawn care services. This could affect jobs, but the purpose of the kit is not to replace people, but to change how they work. If the mundane task of mowing could be automated, then lawn care services can turn their attention to other parts of the lawn that could need care. Lawn care services do not just mow lawns, but if they were able to automatically mow lawns, jobs could be more efficient and require less physical labor. Initially, it may feel strange to witness an unmanned machine operating within a familiar neighborhood, or jobsite. The RetroFit Kit will be the first technology of its kind to transform existing equipment into an automated technology in the lawn-care industry.

Economically this could affect a lot of businesses, because they could be able to mow more efficiently. This could lead to more business for the companies. There will be large-scale automated versions of lawn mowers hitting the lawn care industry soon, because small-scale solutions exist. This would allow businesses to keep and reuse their old mowers, and also lead to less waste. Small lawn care businesses could integrate this technology and decrease the cost for a startup by achieving labor output without having to pay an employee for the lawn mowing completed.

The programmability of the RetroFit Kit is intended to be run off of one universal program that is compatible with every make and model of commercial zero-turn lawn mower. The programs utilized within this technology could be adopted and used in other fields, leading to more opportunities for automation in other industries. The smart-technology residing within the RetroFit Kit prioritizes safety before anything else.

This device is intended for the sole use of automated lawn mowing and we are not responsible for any misuse of this product. Integration of the RetroFit Kit into modern society is nearly a necessity at this point.

**6 LIFE-LONG LEARNING**

Within the realm of automation lies the appetite for more. The technologies utilized will more than likely be enhanced at some future point in time and there will be more effective tools to utilize in the design of the RetroFit Kit. The relationship between artificial intelligence and humans will continue to develop in time, and hopefully automation will be more widely accepted as an asset. Improvements to this relationship are to be considered and developed over time. Significant data could be obtained as lawn care could be operating with AI as well as humans to complete tasks at hand. Efficiency of the RetroFit kit compared to the average employee could prove useful in the future.
A big thing that can be learned from this project is the engineering design process. Taking a design from an idea to a prototype is a big endeavour, especially a project that requires mechanical, electric, and programming component design and testing. Learning about how to research and take the process step by step to create an optimal design and then build it part by part is a large lesson being taught to the group over the course of this project.

An important lesson this project has taught the group is to focus on the engineering objectives of the project and make sure those are prioritized over everything else. As engineers it is very easy to jump ahead of the process. It also becomes a fault to put effort where effort is not deserved in the progress of the design. It is pointless to design a secondary feature for the RetroFit Kit like headlights for the lawn mower when there is no steering ability created thus far. There is a large amount of research that is required in a project of this magnitude that is time consuming, but the more research found about what is already created and available to us then the better the final prototype will be.

Plenty of skills will be learned or reinforced from this process as well. Electronic design is a large aspect of the project and how to design the system so all the parts work together, with the correct power and voltage limits. The group will be learning how to effectively wire the whole system, so that safety is kept in mind, as well as effectively use the space available to integrate the kit seamlessly into the look of the lawn mower.

CAD design and prototype testing is a very important engineering skill that the group will have a chance to experience during this project. Mechanical design and calculation skills will be reinforced as the device will have many restrictions and limitations to abide by.

Programming will teach a lot, because designing a program from the ground up is a huge task, as well as on a system that is not very familiar to us. Learning the Raspberry Pi platform is a hefty task for this project, but experiences with Arduino and other microcontrollers allow for an easier entrance to learning Raspberry Pi. Getting more experience with Python will be good as well, and a lot will be learned about Python development. There will be a lot of development skills from this, as well as debugging and problem solving. Thinking about real constraints like the timing of programs, and how algorithms can affect safety, will be good practice for the real world development of programs.

7 BUDGET AND TIMELINE

7.1 Budget

The retrofit kit intended to automate common zero-turn lawn mowers is a faculty sponsored project out of Northern Illinois University. Within the realm of university projects, a budget of $1000 is allotted to cover for all potential resources needed to effectively solve the problem. The goal of creating this budget is to account for all anticipated costs within the design solution of the retrofit kit, as well as deciding how much of the budget should be allocated to each of the design elements.

Within the budget, there are many subcategories to potential charges that may accumulate over the course of this project. The categories for potential cost include gathering raw material, outsourced material, manufacturing of elements for the project, and possible tool and equipment
needs. Some of these prices could be a bit more than necessary, but it is important to overcompensate in the case of emergency budget usage. Note that many of the products listed below are generalized as the specific models of each respective element will have to be determined further along in the design phase of the retrofit kit for self-propelled zero turn lawn mowers.

*Raw Material Costs*
3D-printer filament - $50
Material choice testing & exploration - $25
Metals - $200

*Outsourced Material Costs*
Raspberry Pi - $30
Rover prototype design equipment - $50
Wiring - $25
Sensors - $50
Motors - $50
Mechanical Parts - $100

*Manufacturing Costs*
Manufacturing fees - $150

*Total* - $730

*it is important to note that these prices are current ESTIMATES.*

**7.1.1 Budget Justification**

First and foremost, the identified need for a microcontroller of some sort comes with the realm of automating something. Without the microcontroller, completing the design of the retrofit kit would be extremely complex, and hard to accomplish with a smaller budget size. The microcontroller is the lifeblood of our project, and therefore allotting a portion of the budget to cover this cost is an easy decision. As far as the selection of the microcontroller goes, Raspberry Pi holds all the desired capabilities necessary for the retrofit kit design solution. Secondly, in order to test the programming of the system being designed, a prototype that mechanically emulates a lawn mower such as a rover is allotted a portion of the budget. The creation of this prototype is essential to the project’s success. The prototype will allow for easily testing and
troubleshooting programming in real time without having to be in a workshop environment with a full-scale lawn mower.

The prototype rover will likely have a lot of the same components the final product will. The sensors and microcontroller are going to be on both, but the main difference will be in purchasing motors and materials to make this rover. This does increase the budget, but thinking about this like a business, the time saved from not having to troubleshoot on a full scale lawn mower outside is greater than the money spent on this. It is a relatively cheap option to create a better design for the final prototype.

Right now for the weather casing of the microcontroller, it could be 3D printed to save cost. A box made out of a light metal would work as well, but since this is a prototype it is easier to modify and build a case with a 3D printer. The case is necessary, so the microcontroller does not get water damage, and short itself. The 3D printed plastic is relatively inexpensive and will serve the purpose of protecting the electronic components from the outdoors. Since the microcontroller housing is really the main physical element to the design process, the ability to test and explore different potential materials is desired. An aesthetically pleasing design that seamlessly integrates itself into its working environment would be the desired outcome as a result of conducting these material exploration and physical testing activities. The amount of money dedicated to these activities will likely be equivalent to the level satisfaction with the finished piece.

Within the realm of design, there is a high probability that preexisting pieces necessary for proper execution of solving the issue at hand are not readily available and may have to be manufactured in-house. At Northern Illinois University, the additive manufacturing lab will allow for proper production of required design components. Part of the agreement when working with many manufacturing labs, is there is a required fee when using their equipment, so for the sake of the project budget, a portion is allocated to manufacturing lab and equipment fees.

Several different forms of technologies will be worked with during this experiment. A handful of computer softwares will be utilized in order to effectively solve the problem at hand. Currently it is known that a Python programming environment and SolidWorks will be required to successfully complete the desired tasks. As part of the budget suggests, since a Python programming environment and SolidWorks are already obtained, there is not much cost to buying software for this project.

All in all, the budget is currently rough estimates of anticipated costs. As mentioned previously, it is better to overcompensate while creating the budget as additional resources may be required for any unforeseen complications that occur during the implementation phase of the retrofit kit.
7.2 Timeline

**October 2021**
- Background Research
- Patent Research
- Basic design requirements
- Market Analysis
- Gather client/customer information

**November 2021**
- Gather starting programming materials
- Gather client feedback
- Understanding physical limitations
- Understanding specific lawn mowers
- More lawn mower inspection

**December 2021**
- Gather rover program testing materials
- Research necessary components
- Start CAD design for prototype
- Material research

**January 2022**
- Microcontroller rover program testing
- Materials research
- Research application design options
- Further program testing
- Commence ordering of materials

**February 2022**
- Start CAD designing prototype design
- Further program development
- Finish version 1 of programs

**March 2022**
- Begin device application to the lawn mower
- Device testing
- Program redevelopment and troubleshooting
- Finalize CAD design for final prototype

**April 2022**
- Research for available parts
- Manufacture CAD design for final prototype
- Finalize Application
- Build prototype

**May 2022**
- Present Project
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Obtain Rover and test programs with rover

Build subsystems

Test and refine final design

Present final design

8 TEAM MEMBERS CONTRIBUTIONS TO THE PROJECT

8.1 Clint Herman

The main focus in the research done by Clint in this project was the physical research done on the lawn mowers. After the first few weeks of market analysis it became apparent that there were no devices in existence that could attach to a previously manually operated lawn mower to make it automated. The patent research showed all of the technology the group could possibly require would be available to us as long as we had the knowledge to implement it. Then the research became focused on the physical limitations and requirements that a current lawn mower provides for a device to be attached.

The steering levers on existing zero turn lawn mowers prove difficult to attach a mechanism that would take over the control of the lever. The space and attachment constraints are drastically different for each mower. This left an immense amount of research to be done and data to be gathered for the group to properly decide which lawn mower was best suited for our first prototype design. The future of the project will also depend upon further research with a larger variety of mowers studied to see if there is any ability to create mechanical mechanisms that will operate multiple different types of mowers.

An equal contribution was made from Clint in all of the writing assignments in the class syllabus. Any physical or virtual meeting the group had Clint attended and was well prepared for.

8.2 Ethan Bode

Ethan contributed to many different aspects of this design project. Throughout the primary research phase of design, it became apparent that there was a gap in the market in which the RetroFit Kit would fit itself into. Ethan became the driving force behind this as he scheduled interviews with several people within the lawn care industry. With the information gathered from these in-person interviews, design constraints were allowed to develop. In addition to the in-person market data gathered, a survey was also created on Qualtrics and distributed to multiple companies within the lawn service industry. This was a form of secondary research and the data obtained from the survey results aided in design efforts.

Following the process of gathering background information regarding the lawn service industry, the mechanical systems within many commercialized zero-turn lawn mowers were
analyzed. This was done in an effort to gain a strong understanding of the working components that the RetroFit Kit would have to interact with. It became apparent that mechanical manipulators were necessary to work in part with the electronic components of the RetroFit Kit to properly automate the task of lawn mowing. Ethan took on the responsibility of designing and manufacturing the central housing unit, and protective units covering the working components of the RetroFit Kit.

Working with Dominic and Clint made the project go much smoother as all team members seemed to assume equal responsibilities within the creation of the RetroFit Kit. Ethan, Clint, and Dominic all equally contributed to the writing segments of the design process, and as a result the quality of work within this project has improved.

8.3 Dominic Heye

The main contributions from Dominic were on electrical and software design. Having experience working with Python and designing circuits with several sensors and motors before, the electrical design was his main focus at first. Helped identify what sensors are needed, because analog sensors cannot be used easily with a Raspberry Pi, and also researched other types of sensors that could be used to further make the retrofit kit better. The electrical design was completed by Dominic, and this was done in KiCad.

Another contribution from Dominic was the software design, which outlined all of the programs and modules that will be written in Python onto the Raspberry Pi, along with how data was going to be stored and managed on the Raspberry Pi. Research on how to effectively use a Raspberry Pi was done, and lots of practice and time spent learning the platform was done. The design of the flow of the programs was completed for the alternative designs paper, and was refined for the optimal design.

Overall, an equal contribution to the papers was done by Dominic and he contributed to team discussion, met regularly with Clint and Ethan to make sure all of the systems flowed together. The work done for the electrical and software design had to be done in conjunction with them, and their efforts in design were effective and helpful to the design for the electrical system and software.

9 CONCLUSION

The retrofit kit for lawn mowers is a device that has great potential to sell, and could affect how lawn care companies mow lawns from here on. The device was designed from scratch, looking at previous designs and what is already out there within the automated lawn mowing market. Each part of the design was taken into consideration, with the idea of safety being put first in each design, to constantly remind the team to design with intent of a safe device.

The retrofit kit will control the mechanical systems of the lawn mower, with opportunities to hold several routes per SD card (which could easily be swapped on a Raspberry Pi). It will have the power to control the speed and direction of the lawn mower, along with the
capability to record and replay routes. This could be an effective solution to the monotonous work of lawn mowing today.

This design could be a very effective design, but this is the very first of its kind. There are lots of possibilities within this design, and it can change as prototyping begins. The device will be prototyped and as that commences, different bugs and ideas may arise, both of which drive innovation and design. The Self Driving Retrofit Kit for Self-Propelled Lawn Mowers can be an exceptional product and the prototyping of the system will drive ideas and creativity.
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11 ACKNOWLEDGEMENTS

We are deeply indebted to Dr. Peter Lin for overlooking our engineering process and providing exclusive guidance throughout the project. We want to thank Dr. Lin for providing a revolutionary project idea for the group to dedicate our efforts toward. We would also like to extend gratitude toward Masters student Alexander Wills for providing structure to the project and encouraging the group efforts. We want to send a special thanks to Dr. Donald Peterson for providing the group with an outstanding opportunity to gather real engineering application experience. The Northern Illinois University Grounds Crew allowed for us to have physical access to several different commercialized zero-turn lawn mowers. Without the help from NIU and their facilities, this project would not have been possible. A big thank you goes out to David Holliday from NIU Grounds Crew for coordinating the group's access to these lawn mowers.
12 APPENDIX

12.1 Updated Specifications

Physical:
  Button interface
  Microcontroller and Battery Housing

Mechanical:
  Sensor Integration
  Raspberry Pi Microcontroller

Electrical:
  Maximum Input Voltage: 12 Volts DC (VDC)
  Maximum Input Current: 5 Amps (A)
  Battery Life: At least 2 hours

Environmental:
  Storage Temperature: -20 to 150 °F
  Operating Temperature: 40 to 110 °F
  Operating Environment: Outdoors

Safety:
  Proper Use:
  ● Hazards installing the kit initially after purchase.

  Improper Use:
  ● If the sensors are not placed correctly, the lawn mower will not stop correctly.
  ● Improper handling of batteries or wires could lead to shocks.

Maintenance:
  Proper maintenance will require cleaning of the kit because grass clippings and other items may dirty the exterior of the kit. The battery will need to be recharged, and will come with a charger that will charge the battery in a healthy way.