Senior Design I: Initial Project Document
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Robotic Solar Farm Grass Cutting System Design Challenge

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1. Executive Summary

The optimal location for PV panels for large generation of energy are normally in open areas such as a grassy field. One of the downsides of these types of locations is the landscaping required from keeping grass and other vegetation cut so it does not hinder the ability of the solar panels and operation of the solar farm as a whole. Solar panels require to be in direct sunlight to run optimally, and that is variable with cloud cover, storms, etc. Thus removing the external factor of grass and plant growth hindering the operation of a PV panel is imperative when running a solar farm. Maintained grounds help with both the proper operation of solar panels and the easy maintenance of solar infrastructure. Properly maintained grounds will allow for easy replacement of a certain panel within an array is not functioning properly, from corrosion or other effects. There are a number of landscaping contractors that specialize in solar farm landscaping.As a result, solar energy is not entirely free and a major expense of solar farms is ground maintenance. There can also be risk with using ground services with possible damage of solar infrastructure which can be avoided if the AI-assisted, autonomous solar powered rover-based robot has good While there may be various approaches for providing ground maintenance service, the goal of this project is to minimize the monthly expense of cutting the grass by using AI-assisted, autonomous solar powered rover-based robots to articulate and guide electric weed whackers.

The main goal behind the eGOAT (electronically Guided Omni-Applicable Trimmer) is to cut the costs and potential risks involved with human ground maintenance. The eGOAT must be autonomous, low cost, smart, and effective. An autonomous system such as the eGOAT should be able to operate without frequent service or interference, while still providing an effective grass cutting service and ensuring the safety of solar infrastructure during operation. As the name suggests, the eGOAT will be powered electrically, drawing its energy from an array of integrated PV panels, unlike conventional, human-operated mowing equipment that run off of fossil fuels and require to be refilled frequently. This means that the eGOAT will be totally renewable, saving both the owner and environment the recurring costs associated with less eco-friendly options. The AI-guided task planning software of the eGOAT will be able to detect obstacles in the environment, identify locations and objects in need of trimming, and construct a sequences of tasks to accomplish mission objectives and avoids any potential damage to important infrastructure.

In the interest of generating many possible solutions to this challenging problem, this project will take the format of a design competition, where multiple interdisciplinary student teams will work in parallel to produce the best possible solution. There are at least three major elements to the project as follows:

- Rover-based Robot: To provide the articulated sweeping motion needed to move the weed whacker across the terrain and cut grass.
- Navigation and Control: To identify grass areas that need attention (i.e., cutting), avoid obstacles and provide overall motion control of the rover-based robot.
- Power Supply: Grass cutting may take place at night and charge during the day. To accommodate such a scenario the system must use a defined battery storage technology with charging capability.

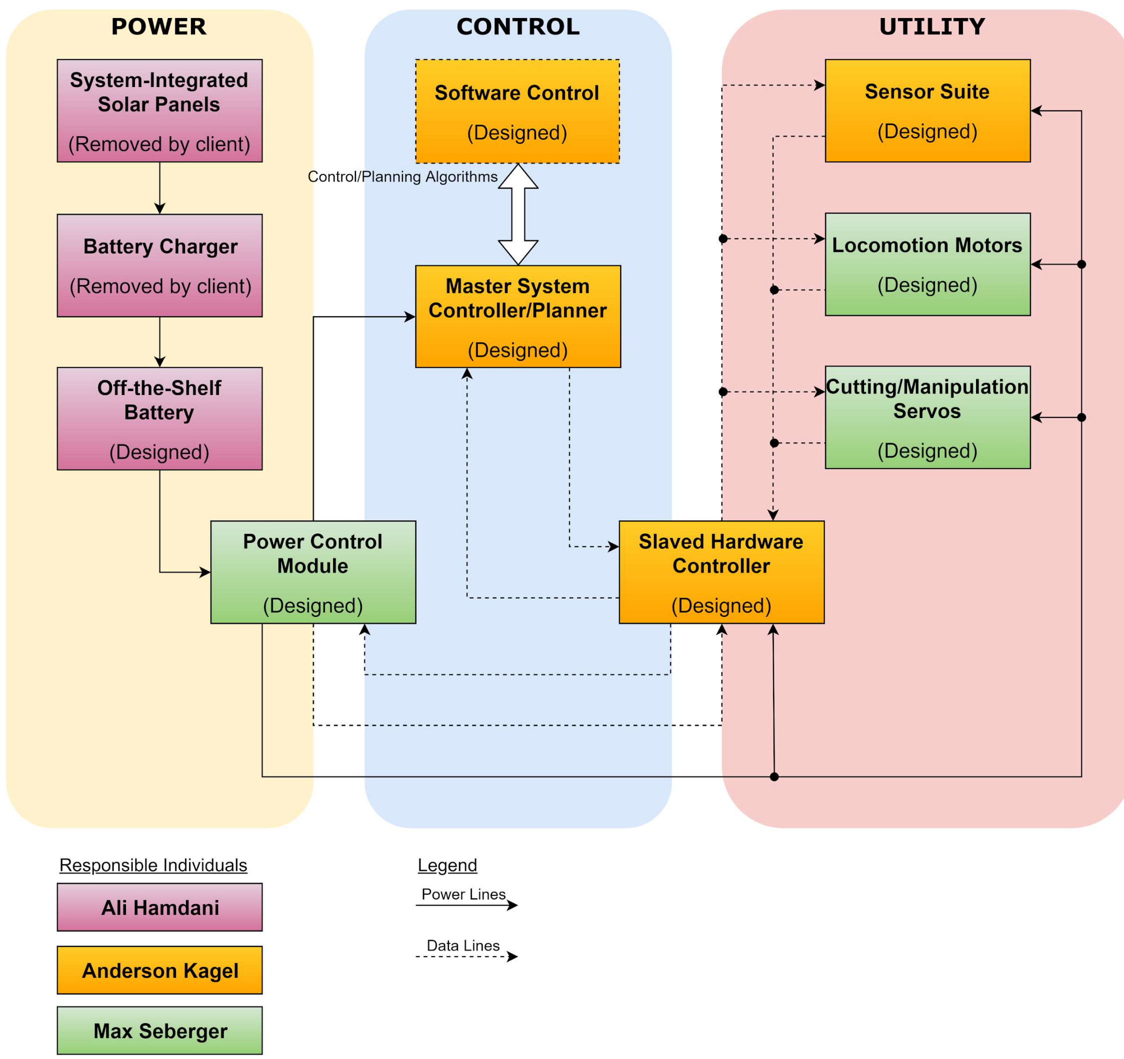
Successful design execution will require an interdisciplinary team with participation from students in the following disciplines: computer science, computer systems, electrical and mechanical engineering. The optimal design will integrate state-of-the-art technology at the lowest cost. Thorough and thoughtful consideration of safety, reliability and durability is an absolute requirement.

The eGOAT is being designed and built in conjunction with a team of mechanical engineers as well as a team of computer scientists. Although there will be significant overlap with these elements of the team and by necessity key elements of their designs will be discussed in detail to provide context, the electrical/computer engineering team (and by extension this document) are primarily concerned with the design and implementation of the electrical and computer subsystems specifically.

2. Project Description

In this sections, we will cover the high level goals, motivations, and intended functionalities of the eGOAT project. We will also delve into the requirement specifications of the eGOAT and how they interrelate with each other as well as with the market requirements as defined by our sponsors. Finally, we will examine a number of existing commercial systems that already exist on the market today and use them as a baseline and inspiration for the development of the eGOAT. **Figure 2.1** below is provided below as reference for the system level architecture of the eGOAT.

Figure 2.1: System Level Block Diagram



2.1. Motivation

Automation is mundane yet critical industrial tasks have become increasingly commonplace in order to reduce the large costs of a human workforce. Automatic machines do not require pay, overtime, benefits, supervision, quitting times or any of the other concerns related to employees, and thus those costs are negated. Negation of immense worker costs is the exact reason this system design problem was presented to UCF students from Duke Energy and OUC. In specific terms, the system design problem can be described as using available, “off the shelf” technologies to create an automated lawn care tool. This machine should meet the customer requirements including ease of maintenance, intelligence beyond that of a “Roomba,” accuracy of trimming all grown surface area, safety to the existing solar farm equipment, safety towards occasional personnel, and an overall capability for Duke Energy to maintain a “hands-off” approach to the agriculture within their solar farm properties. This lawn care is critical due to an overgrowth of the grass and weeds within the area, directly and indirectly, impeding the power gathered by solar cells and causing potential damage to the solar panels through their growth. The current methodology of maintaining the grass within the solar farms, similar like with most lawn care, requires the hiring of human personnel with high labor costs due to the value of their time, the difficulty of labor within the environmental conditions of direct sunlight and heat, and various heavy duty pieces of equipment rather than one end-all-be-all tool. With an automated, singular device, even if the same amount of lawn care requires a longer time to complete, the cost offset due to lack of human interface, low concern for oversight, ease of maintaining only one piece of equipment, and accuracy are the key benefits to customers such as Duke Energy, or even towards a secondary market such as all non-commercial lawn owners.

2.2. Goals & Objectives

This project aims to build a fully autonomous rover-based grass-mowing robot for maintaining large solar fields. The product is expected to be minimally maintained and operate without human intervention. In a clean environment, these robots might be expected to operate without error and without need for maintenance, but in the large solar fields the customer operates, there is the possibility of the damage from the environment and of getting lost. Additionally, the solar fields are often in remote locations without much nearby infrastructure or ability to deploy such infrastructure. This suggests a need for a high degree of autonomy and intelligence within individual eGOAT units, as well as some form of communication to facilitate the monitoring of and manual remote control over each robot.

This project is intended as a step toward making solar energy cheaper, more autonomous, and ultimately more viable in the long run. According to OUC

(Orlando Utilities Commission), the annual cost for maintain one field of solar arrays is between $150K and $200K – a number large enough to drive down the cost efficiency of solar energy. Keeping grass fields for solar farms has few real benefits over paved cement ground or fields treated with pesticides, except that the former amounts to a cost prohibitive startup expenditure, and the latter is against the interest of the customer, who also acts as a water utility, and in the end pesticides are just an alternate maintenance cost. Their goal in approaching UCF and our group with this project is to cut the current monetary drain that is hiring human labor for grounds maintenance. Not only are the humans expensive, but they also leave a larger carbon footprint, with the use of gas-powered maintenance tools.

2.3. Requirement Specifications

The requirement specifications have been brought to our attention by us the project creators and our sponsor. Understanding what our sponsor requires helps us in our design and requirements in order for those requirements to be fulfilled.

2.3.1. Physical Requirements

1. The eGOAT shall be capable of navigating uneven terrain with an approximate terrain differential of 3 inches over a 2 foot span.
2. The eGOAT shall be able to maintain a grass height between 3 and 6 inches.

2.3.2. Hardware/Electrical Requirements

1. The eGOAT shall be equipped with a remote kill switch that can turn off the cutting system and locomotion at a distance of approximately 50 feet.
2. Power system shall have overcurrent protection
3. Will utilize battery at higher voltage than required voltages
4. Printed Circuit Board will incorporate power management modules
5. Power system shall step down and regulate power source voltages
6. 5V step down module will have a max current of 2.5A
7. 3.3V Step down module will have a max current output of 2.5A
8. Power System will reduce PCB footprint with use of integrated circuits
9. Power system shall utilize efficient and minimal amount of batteries
10. USB outlet ports will be utilized for direct connections of power and data

11. Batteries will be protected from transient signals
12. Off the shelf components will be external to pcb
13. Power loss will be minimized through wiring and connections

2.3.3. Software/Autonomous Requirements

1. The eGOAT shall be able to autonomously navigate its environment.
2. The eGOAT shall be able to sense objects in its surrounding environment and avoid damaging infrastructure, environment, and humans.
3. The eGOAT shall be capable of both cutting grass in large, open areas and trimming close to solar farm infrastructure.

2.4. House of Quality

The House of Quality, as shown below in **Figure 2.2**, is a design tool that the eGOAT design team has used to better understand and communicate the relationships between the marketing requirements of Duke Energy and OUC and the engineering requirements derived thereof. This tool has been especially important for the eGOAT project given its interdisciplinary nature and has aided the various teams and disciplines in focusing on the same end-product goals.

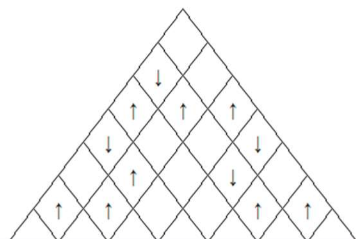
The marketing requirements were extracted from a combination of the original documentation sent by the customers, a lengthy interview process in which we clarified and refined the requirements of the customers, and from our own intuition and discussion of what would be desirable traits for the product to have. Perhaps one of the most obvious marketing requirements we extracted was cost, which in the case of Duke and OUC (as the sponsors of this endeavor) includes both the cost of final construction *and* the cost of development; needless to say, they would like this metric to be "as low as possible". The size of the final product also became an important consideration, not only because it affects ease of deployment and raw material cost, but more importantly because it heavily affects the system's ability to maneuver in its environment so it would preferably be as small as possible.

Another significant factor in the product's design would be its speed, as one of the criteria that it will be judged on is the time required to mow a specified area; additionally, the product will be judged on the time required to fully charge its batteries, and so both its speed and charge time should be as fast as possible. However regardless of how we optimize the solar charging subsystem, the product will still be charging a large battery using solar energy that is independent of the existing solar infrastructure and will take a significant amount of time to recharge the battery after it has been depleted. Therefore, it is also critical that the system is capable of operating for long enough duration of time in between charges to complete a significant amount of work before needing to enter its recharge state. We must also consider the potential hidden costs of this product: the system must be easy to install and operate safely amongst the existing workflows of the sponsors' solar farms so as not to induce an opportunity cost by interrupting normal operations with a lengthy installation or additional safety procedures.

Figure 2.1: House of Quality

Objectives	
To Maximize	+
To Minimize	−

Relationships	
Strong positive corelation	↑↑
Positive corelation	↑
Negative corelation	↓
Strong Negative corelation	↓↓



Row #	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Direction of Improvement	Effuciency	Cost	Enviromental Resistance	Battery life	Accuracy	Weight	Dimesnsions	Row #
			Column #		1	2	3	4	5	6	7	
			Direction of Improvement		+	−	+	+	+	−	−	
1	8		Cost	−	↑		↑	↑				1
2	2		Size	−	↓	↑↑		↓		↑	↑↑	2
3	4		Speed	+	↓	↑		↓	↓	↓		3
4			Charging time	+	↓			↓				4
5			Duration	+	↑	↑		↑↑		↑	↑	5
6			Ease of Installation	+		↑				↑	↑	6
7			Safety	+		↓	↑			↓	↓	7
			Target		>75%	<1500$	Resist 45 mph wind,water proof	>3 hr	>80% spent over grassy area	<30lbs	<2 feet in all directions	
			Column #		1	2	3	4	5	6	7	

Equation 2.1: Definition of Power Efficiency

$$Efficiency = \frac{\sum_i \eta_i (L_i)}{L_{system}},$$

$$where\ \eta_i\ is\ the\ efficiency\ of\ the\ i^{th}\ component\ and\ L\ is\ a\ resistive\ load$$

In response to these marketing requirements, we have identified a list of engineering requirements and metrics that we believe are the most important factors in meeting these needs for our sponsors: power efficiency, cost, environmental resistance, battery life, accuracy, weight, and dimensions. Using the definition of efficiency shown above in **Equation 2.1**, we plan to measure the properties of our electrical components and calculate the overall power efficiency of our system and aim to maintain an efficiency greater than 75% overall. When we accepted this challenge from our sponsor they set a maximum reimbursement amount of $1,500, and we plan on keeping our total product and development cost below this figure. When considering the operational environment of our product we were primarily concerned by Florida's climate. Simply put, Florida is not friendly to the longevity of any engineered system and even on the best days the humidity alone can be fatal to any unprotected electronic components in a relatively short amount of time, let-alone the commonality of storms; therefore, the decision was made that the entire system would be waterproof and capable of surviving exposure to any water conditions short of flooding or submersion. In the interest of meeting the aforementioned duration requirements, the battery will be capable of supporting at least 3 hours of continuous operation before requiring to be recharged. Additionally, in order to improve the speed of task completion as well as the efficiency of battery usage, the system will be capable of accurately recognized unserviced areas and avoid wasting time and energy moving across already serviced or non-grassy areas, spending greater than 50% of its time over unserviced areas. Finally, to help improve speed, maneuverability, power efficiency, and accuracy the system shall weigh no more than 30 lbs. and measure less than 2 ft. in all dimensions.

2.5. Existing Designs

Analysing existing designs is important for creating a product or project because it gives you the edge of what can be added and improved. When designing the eGOAT we research existing designs and products on the market to compare what is used in the market and what the eGOAT needs to change or adapt to fulfill its requirements and constraints. There are many autonomous household products that are on the market that use features that the eGOAT would need. We want to make comparisons with the products and our project with the following factors in mind: Operation, safety, power usage, innovative control, and price.

2.5.1. Automower by Husqvarna

The Automower by Husqvarna as seen below in **figure 2.3** is an existing product on the market that is an autonomous robotic lawn mower. It can "Navigate complex lawns, mow both day and night, operates with minimal noise, works safely around people, and resists theft". This product can operate on slopes up to 24 degrees claiming that it has "Large Driving wheels".

Figure 2.3: Husqvarna Automower

When it comes to safety of the Automower, it will stop operating blades if the unit is "slightly" lifted. It "gently moves around the yard" and it has non fixed blades. Using an application installed on your mobile device you can command the unit to start mowing, park , and inquire what it is doing at the current time. There is no information about a "kill switch" for safety which can be dangerous for anybody who gets close to it.

In terms of navigation of this system the boundaries must be established by the user using boundary wires. This could create a problem with parts of the lawn being uncut and growing to an undesired length. The Automower also can return to its charging station after the set operation time is over or if the user commands it to do so. The Automower has a work capacity of .25 acres, with a 58 db sound level. It can charge within 60 minutes. The Automower retails on Amazon for $1,783.56

2.5.2. Honda Miimo Junior

The Honda Miimo shown below in **figure 2.4** is another product on the market that is a robotic lawn mower, this one being made from a large company. The Miimo claims it is low in noise, and waterproof. It is capable of operating on slopes up to 25 degrees and has high traction. It can be controlled via mobile device application and the user can control the cutting height of the blades. In terms of safety the Miimo will stop blades instantly if the system is lifted or tilted. There is no information on a immediate "kill switch", the closest feature would probably be the parking or charging feature via mobile application. The Miimo uses a 22.2 V battery to operate for 40 minutes. The Miimo operates at a 62 db noise level making it quiet and causing the least amount of distractions.

Figure 2.4: Honda Miimo Junior

2.5.3. Comparison to our project

The products mentioned are excellent examples to adapt and expand from when designing our system. One understanding to have is that these products are meant for residential properties and for everyday family household consumers. Although both having a central purpose to mow grass and maintain grounds there is a difference in the specific type of grounds. The residential household lawns seem to be a lot more uniform and generally consistent throughout the area. Commercial grounds need more work capacity and need to be able to handle tougher types of grounds. The eGOAT is being designed to operate for a public utility's property which needs to have more complexity in how it operates and handles specific tasks.

There are many features that the products on the market and the eGOAT will share. Being totally autonomous is the obvious shared feature, being able to navigate without supervision within a given parameter is what both the products and the eGOAT will deliver on. One difference is in how the parameter or boundary is configured, the products mentioned have a parameter established by the user given physical guide or fencing wires. The eGOAT will most likely be gps bounded for the majority of the area needed to be mown, with only crucial or very sensitive infrastructure being guarded by wire and fence if required. For example if the eGOAT needs to operate along an “aisle” along the the PV panels there would be guided wire or fencing that would allow minimizing the distance from the string trimmer to the solar farm panels.

One feature that both products could have that has not been totally thought out for our project is being able to operate on a slope. Both products can handle a slope of at least 20 degrees. Although the land eGOAT should be consistently flat, being able to operate on slopes would be a huge benefit for the overall quality of operation if need be. There is also a difference in mowing with the products and the eGOAT’s requirements. The products mentioned use blades , which are heavier , although very conventional, and would require a larger motor to operate them. The eGOAT will execute mowing using a string trimmer or “weed wacker”. Using a different tool to mow the lawn should be lighter and less complex should mean that the eGOAT uses less power. There are sme sensors that would not need to be utilized if in fact the eGOAT becomes waterproofed. Using a rain or precipitation sensor could be avoided because there would be no use in sensing moisture if the system is waterproofed. The two products shown above in **figure2.4** and **figure 2.3** display waterproof designs.

A “kill switch” as a big safety requirement is one that has not really been discussed with these products. The safety features of these products mention powering off if they are lifted or tilited which would expose blades but no information on a “ kill switch “ a switch that in any emergency in any situation would immediately power off the lawn mower. Since the eGOAT will be operating on grounds with very important infrastructure and being a workplace with legal ramifications for injured employees, a kill switch will most certainly need to be necessary to avoid disasters. The eGOAT should definitely adapt, along with a kill switch, a system shutdown if the system is tilted or lifted for any reason whatsoever increasing the safety parameters when operating. The two products allow for user control via mobile application which is connected by bluetooth. This would be a safe and easy way to control the eGOAT like starting and scheduling its operation, displaying status of operation, and ending operation immediately.

From the comparisons of the products the batteries we would need modeled off them would be around 24 volt rechargeable batteries this is a good point of reference for what we need to help power the eGOAT. Comparing the prices of these products with the budget to create the eGOAT , we should be under or at the minimum price for this type of product. Again our project will have more complexity because it involves important and very specific safety and operational requirements. There is no doubt that the features that these products have would be perfect for our project.

3. Design Constraints & Standards

The eGOAT must use an off-the-shelf, battery powered, string-based trimmer. This constraint on the design helps ensure that we will be using a high quality trimmer. Making sure that it is “off-the-shelf” helps with the ease of selecting and the ease of connecting it to our system. Along with the trimmer ,having an the eGOAT use an off-the-shelf battery and charger creates a design constraint in the sense that the type of battery we are looking for that we believe would be great fit could be unavailable. This forces us to use something that could change the power designs.

The eGOAT must operate independently and have no attachments to solar farm infrastructure. This constraint does not change our design because our project will be totally independent of any charging needs from such a high level system. If charging is necessary we will attach a solar panel to the eGOAT. It would help to have a high level system of power to charge our eGOAT but we can easily work around this constraint.

The eGOAT must not exceed an estimated budget of $1500 for total material and assembly cost. The financial backing needed to order parts for our design is important, if a higher budget was given we would have the ability to design a robust system with a very high level performance. The eGOAT must be limited to a size of 2 feet in each direction during grass cutting operations in order to fit between/under rows of solar arrays.

3.1. Economic and Time Constraints

Economic constraints can hinder on creation of a project. We want to minimize as much as we can so every team for the project has a chance to order what they want for their priorities. The economic constraints that are being imposed are that the eGOAT must use an off-the-shelf, battery powered, string-based trimmer, off the shelf battery and charger, and must not exceed a budget of $1500 for total material and assembly cost. These economic constraints affect our financial situation because they force us to purchase expensive products potentially leaving us with less money needed to buy other components. Having more money can allow us to bypass efficient design and if thought carefully may possibly bring a better and cheaper product depending on the type of components one uses. When keeping up with other products on the market we want to find a way to minimize the cost of our project. This will help ensure that we have a working product at a low price to use it thus increasing its popularity. Along with economic constraints there are time constraints. Due to the nature of this project we are limited with a 2 semester, roughly 8 to 9 months, to design and build this project. That time frame is not a time frame where all project members will have their full attention to the project because of academic responsibilities. Along with that the other disciplines have a different schedule to abide by so the schedules for design and ordering parts are out of sync which can cause problems with fluidity of design and construction of the eGOAT. This hinders on the design, testing and time to build it, and possibly can cause a “rushed” project. Creating products on the markets take considerably more time and attention so this would be one major downside if the project were to compete with products on the market.

3.2. Environment Constraints

The eGOAT is not supposed to harm the environment it should help sustain it. We the fact that the eGOAT will be totally electric helps erase any carbon footprint we we would have on the environment. In terms of the operating environment we would have to operate with a limited size, with no dependency on solar farm infrastructure and must not damage anything or anybody on the solar farm. The eGOAT. Using all electric motors and no gas power can cause a problem to move the eGOAT. The eGOAT must totally rely on one option , electric. This can cause problems if it is not totally well designed and has flaws. Although the environment will not be harmed , the operation and quality of the eGOAT may.

When it comes to performance the environment can bring a number of factors that can hinder on the performance of the eGOAT. The grass height is one that can cause problems with our system to move at the anticipated speed to perform the full task. Grass height along with the uneven surface of the ground and dirt can bring more resistance electrically for the eGOAT. This causes us to design an electric system with a bigger current draw threshold. Along with the height of the grass, the thickness also can affect our system from moving fluidly. Thickness can be a summation of factors like, grass density , and wetness of grass for precipitation. When we discuss environmental constraints the existence of infrastructure. These will be obstacles that can harm the eGOAT’s structure if it were to collide into the infrastructure. This constraint is the freedom to operate anywhere.

3.3. Social Constraints

Social constraints in this project overlap with other constraints for our project. If the eGOAT were to be sold on the market there are a number of precautions it must take to operate and have good social standing among consumers. The eGOAT must not damage infrastructure, environment, or humans. These are almost “no nonsense” understandings especially when it comes to the social aspect of the project. If the eGOAT were to damage any of the conditions listed above there could be social backlash that could lead to a decrease in popularity and consideration to buy and use our project. Our goal for this project or any product is to have good social standing among the customers that would use it. We do not want to use materials that are harmful or can cause social backlash like using a certain cheap part from another country that is under scrutiny.

3.4. Political Constraints

The political constraints associated with our project overlap with other constraints but still have a huge role to play. The constraint of the eGOAT must not damage infrastructure, environment, or humans is a very political constraint. All three conditions especially infrastructure and environment are politically motivated at times in this country. If the eGOAT were to damage public infrastructure that can lead to people being withheld from a certain utility or critical part of operating in this country. For example if the eGOAT were to damage solar farm panels that could lead to a higher cost of electricity for the consumer and hurt the reputation of the project and the owners of the farm.

3.5. Ethical and Safety Constraints

The ethics of designing the eGOAT should have a high priority when designing. “Cutting corners” so the job gets finished is not an option when it comes to the constraints that the eGOAT must not damage infrastructure, environment or humans. A reason these conditions could not be met could be the because of lack of time to finish the project. Knowing that anything can go wrong in any outlier of a situation, we would strongly advise that humans be protected from the eGOAT. Designing features to make sure it does not go on to further hurt people or animals would be one that we highly prioritize. The ethical prioritization of our project is key , it should go as follows: Not damaging anything or anybody , cutting all the grass, and not disrupting operation of the solar farm.

3.6. Health and Safety Constraints

The eGOAT will be operating on a job site , will have electronics on board, and will have cutting tools on it. Safety needs to be a main concern when designing the eGOAT because of its potential to hurt and injure people. The constraint of an off the shelf battery powered string based trimmer is one that helps this cause. Making sure that we use a trimmer that is in use for the residential and consumer level means that it should not act in a volatile manner. Along with the trimmer is the off the shelf battery and charger that will be needed. This helps our safety factors because it will be a battery that is being sold to the general public and is regularly tested. This all ties into three other conditions of not damaging infrastructure,environment , or humans. Safety wise if a solar panel array is damaged an inverter could be damaged and cause harm. There is a lot of electricity being generated in such a distributed amount of space there is a possibility that that causes a safety hazard in the area. Environmentally we would want to help keep down carbon emissions and footprint on the area of operation. This is all being rectified by being totally electric and totally independent of any fossil fuel source. If electronics are exposed to harsh conditions there can be a possibility of a short circuit and maybe a fire. This would cause great harm to the environment and people around it. The help of the off the shelf components would rectify this problem but the added protection should be in place to stop any sort of situation from happening.

3.7. Manufacturing and Sustainability constraints

The eGOAT will be battery operated which does some harm to sustainability. The battery has an operational life that can increase the replacement of the battery every so often. Since our sponsor does not require any charging mechanism the battery must be replaced every so often since it will run out of charge. The aspect of this is that sustainability gets minimized and will require time periods of no operation due the matter of replacing batteries. This puts us at Another component on the eGOAT that will compromise is the motors. The motors are brushed dc motors that will have a problem with friction of the brushes. They will wear out at one point and the drive system of the eGOAT will not function as intended anymore. The string trimmers may also wear down due to the amount of grass it comes into contact to constantly. This will dampen the amount of trimming that will actually be going on and will also need to be replaced. The structure of the eGOAT which includes the wheels may also be compromised. The rough terrain will be a design constraint but for a very long period of time the structure may give way and cause a rebuild or refurbishment to take place in order for it to fully be functional. The structure not only holds everything together is houses the electronics and important sensor components that hold everything together. Since the the eGOAT will be operating outside the wire connections may take wear due to the heat or environmental harm that takes place on it. The the higher the temperature of wires the less efficiency they have in transmitting voltage and signals across, this may lead to replacing wires to its connections which minimizes its sustainability.

OUC and Duke Energy have been trying to mitigate the growth of grass at the solar farms where the eGOAT will be operating. With added help with getting rid of grass and plants the eGOAT will have an easier operational use and will be able to be sustained over the more time. If there is less resistance on the eGOAT then it will survive and be sustained for longer. This helps the case of our project and creates an affordable situation for the user and the project creators when it comes to using it over again.

3.8. Applicable Standards

This section contains any standards that may be applicable to the eGOAT project. Standards are important because they help create a project in a systematic and orderly design. If a standard is used for a project , if anything is to go wrong with the project , repairing or even redesigning the project will run smoother because of the standards used in the design.

3.8.1. Electrical Standards

This section contains alls standards pertaining to electrical design.

3.8.1.1. QI Wireless Charging Standard

QI Wireless Charging Standard is an open interface standard that was developed by Wireless Power Consortium. The standard is used for inductive charging for up 1.6 inches in distance. Devices that use the QI standard will need to use electromagnetic induction. A QI system has two requirements , a base station , which is a transmission pad that will be connected to a power supply and have inductive power. Base systems should have an interface surface.

3.8.1.2. Battery Standard

The battery standard IEEE Std 1013-2007 talks about the uses of lead acid batteries for PV systems , which would be solar panels in the eGOAT's case. The standard will help with the types of lead acid batteries that we can choose from in terms of parameters like safety. We would need a battery for a PV system because of the contingency of having more load than the solar panels can operate for. For this case if the eGOAT is not operating at an optimal time for the solar panels to operate at peak times then the battery would be used to manage the load: This falls under an "Autonomy" in the standard, which defines the time the load would be powered by the battery.

The battery's load is the current that is created between the battery and load circuit. When it comes the current , there are types of current situations we must be aware of. Starting current: the current drawn when the system is powered on initially. Parasitic currents: these are currents that are drawn from measurement devices like a charge controller. These are all the factors of current that need to thought about when designing. When it comes to temperature of the battery the temperature is directly proportional to the capacity of the battery. Designing this system will take measures like knowing the time the battery will be used, the amount of current that will be drawn from it.

Of course without a battery the eGOAT would not be able to run if there was not existing energy source like a solar panel. This standard would help our design in terms of the calculations we need to prepare so our system is fully functional and there are no contingencies that occur. Understanding the Autonomy of when a solar panel can not handle a load a battery takes over is key because it assists in our calculations for load and time of use for the battery.

3.8.1.3. J-STD-001 F: PCB and Soldering Standard

The J-STD-001F is an industry standard that prescribes practices and requirements for the creation of soldered electrical and electronic equipment. The purpose of this standard is to describe materials, methods and acceptance of protocol for the completionion of electrical soldered equipment that shall be both safe and of a high quality. Through the application of this document it shall provide quality control for manufactured products that contain a soldered electrical and electronic assembly. There is two other documents that may be used in conjunction with this standard that help provide clarity in its implementation by providing both visual assistance and additional information. IPS-HDBK-001 is a handbook and guide meant to supplement J-STD-001F and gives additional information relating to the processes and “how and why” the current processes are being used. IPC-A-610 F is a standard that shows a collection of visual quality for the acceptance of requirements for electronic assemblies.

This standard contains classification of electronic equipment that is determined by the end-item use. There are three general classes that are used to describe the final product and they are determined by functional, Performance, complexity and other considerations that relate to the quality of product being produced. It is possible that equipment can have overlaps between classes. Class one refers to General Electronic parts and includes products where the major requirement is functionality of the final assembly. Class two refers to Dedicated Service Electronic Products and includes products that require long lasting performance and extended life. Class three refers to High performance Electronic Products and includes products that require a continued high performance or high performance on demand. The product classification that the eGOAT’s fits into is both class one and class two. Class one procedures will be followed for the design and building of the eGOAT because class two standards will not be needed till the industrial application of the eGOAT come into play. The **table 3.1** list general specifications that will be used with the fabrication of the PCB and will be used regardless of class.

Table 3.1: Design, Fabrication and Acceptability Specification

Board Type	Design Specification	Fabrication Specification
Generic Requirements	IPC-2221	IPC-6011
Rigid Printed Boards	IPC-2222	IPC-6012 IPC-A-600
Flexible Circuit boards	IPC-2223	IPC-6013
Rigid Flex Board	IPC-2224	IPC-6013

The major elements that are covered in the J-STD-001F are flux, solder paste, solder alloy and soldering system. Whenever one of these processes are changed it is important to check that the new one still adheres to the standard. Soldier shall be in accordance with J-STD-006 which describes requirements and test requirements for electronic grade solder alloys for both fluxed and non fluxed. Solder that is considered lead free should be used as a preference and should contain less than .01% by its actual weight. The solder paste that shall be used in accordance with J0STD-005 which is a joint industry standard for the testing and specification to produce high quality electronic connections.

This soldering standards includes many more important considerations in the design and building process. This standard lists requirements that include instructions for surface mounting, through hole mounting, wire setup and general soldering and assembly requirements.

3.8.2. Software Standards

This section contains all standards pertaining to software design.

3.8.2.1. C Language Standard

ISO/IEC 9899 is an International Standard which talks about the different ways and methods you can use the C language and how to implement it. The standard talks about several different sections about C: Scope,Terms and definitions, conformance, environment, language, and library.

The Standard’s scope goes over the topics like the representation of C programs, the syntax, and semantic rules for interrupting programs. The standard starts off defining key words that are used within C program. This standard applies to software design which will be used in the software aspect of our project. There are list of definitions and rules that have been given in the standard that will help understand the standard in its entirety. In the standard there are a number of environments that are defined. A freestanding environment is where a program execution can operate “without any benefit of an operating system.” The standard has a section in it that explains the language, topics like notation , concepts, and conversions. The standard explains different types that can have values to them. The types range from integer , character, floating , array , structure,boolean, and pointer types. These all have their own attributes and can be used in specific types of executions.

3.8.2.2. Arduino IDE & Language

The Arduino integrated development environment (IDE) is a software development platform with integrated toolchain that is widely popular amongst hobbyists and professionals alike. Because of its widespread popularity in both prototype and product scenarios and the open source nature of its toolchain, it is widely supported by many microcontroller manufacturers and integration libraries for a large number of other products.

The language of the Arduino IDE is essentially a dialect of C/C++ augmented with a library with common microcontroller functionality and slightly different source code formatting rules. Rather than a *main* function as in standard C, and Arduino requires a *setup* and *loop* function to run which are then linked to a stub *main* function at compile time. The linked code then is then compiled with the standard GCC toolchain and the resulting binary is encoded as a hexadecimal representation within a plaintext file that can be serialized into the microcontroller’s memory. So long as the microcontroller supports this method of compilation, this allows developers access to an extremely rich, highly cross-compatible library and easy installation without losing the advantages of bare metal programming.

4. Operation Manual

This section shall contain the correct operation of all subsystem and systems of the eGOAT. This will allow easy setup and understanding how to operate the eGOAT.

5. Research

This section shall contain all prevalent research that may benefit the eGOAT in creating a design that meets all requirements set in the requirement specification.

5.1. Power

The main focus for powering our project is what is going to be utilized , how much load is needed, and what will be the source of power. Understanding how much power is needed for each component along with the most efficient way of configuring a battery(s) to components to minimize loss. Demonstrating power will be most likely in the form of a Printed Circuit Board or PCB.

5.1.1. Power Requirements and System Viewpoint

Many devices like circuit boards, microcontrollers, computer boards and motors will be the main loads of the system. A battery with sufficient capacity and the ability to supply a surplus for reliability is needed. Understanding capacity will come from the power demands of the components needed which will be taken from data sheets and voltage and current tests of each component. For this project power consumption may not be constant for a given period of time. External resistance might be a factor that creates an irregular consumption of power which could be lower or higher of the limit calculated. An example could be if the system needs to turn or move through tougher terrain motors would be faced with higher resistance which would increase their power demand. Regulating voltage will be an important component of the system for the unknown loss and external resistance may require less or more power. A passive voltage regulation would be used if the battery distributes more voltage than required. The goal of a passive voltage regulation is to reduce the input voltage and converts to the required specified voltage. Creating a stable system is important due to the fact that there is a multitude of essential components that rely on continuous quality power.

5.1.2. Solar Panels

Solar Panels are a renewable source of power that are used in a lot of industries. The main usage of solar panels for our project if we were to use them will be to charge a battery and power auxiliary components if needed. Solar Panels are made up of solar cells which are made of silicon. The cells are made up of two different types of silicon, P and N. The PN Junction, is a configuration of a P side and an N side that both help let electrons establish a positive and negative polarity. When sunlight is cast upon a solar panel , the photons that make up the light are what the panels feed off of. When the photons hit the solar cell a “hole” is created within the PN junction. The hole breaks the bonds of the electrons and lets them free and they naturally flow to the N side of the PN junction. The electrons that are free then flow through a connection that leads them to a load , thus creating a current. Solar panels are made up of many cells depending on the size of the demand. Solar Panels output a DC power signal so for many appliances that require an AC power supply, an added inverter will be required to satisfy that requirement.

Solar irradiance is a measure of the power from the solar rays hitting the panel. Irradiance can be measured wherever the sun effects so space and the earth’s surface are the main locations. A high irradiance position is the goal when positioning a solar panel because the maximum power is imperative for optimal output.

For this project solar panels may be utilized by helping charge the battery required for our system and also may be used to power auxiliary components of our system where found fitting to use. For optimal output from a solar panel there are a number of factors that require to be accounted for. Panel output can be hindered through minimal shade from trees, or even from debris on the surface of the panels. Solar panels also need to be tilted at a certain point of the year depending on the season due to the position of the sun.

We have decided not to involve solar panels into our design for the eGOAT. The eGOAT would not benefit from the solar panels because of two factors. First our sponsor does not require a charging station so a solar input is not required. Second based on the design of the eGOAT, a charging input from solar panels would not be substantial enough and would hinder on the weight , space and budget of the eGOAT.

5.1.3. Charge Controller

A charge controller needs to be utilized for the project and it is very useful when it comes to managing charging levels. It prevents overcharging,discharging and trickle charge of the battery which helps sustain battery life. There are two different types of charge controllers we can use. One type is called an MPPT which stands for Maximum Power Point Tracking. Its a method to use the maximum power from a solar panel. The maximum power point can vary over time so it may or may not be the same all the time due to factors like ambient temperature or the temperature of the panels itself. The mppt compares the voltage of the panels and the battery voltage then calculates which voltage is the optimum voltage and the maximum current to direct into the battery. The other type of charge controller that can be utilized is a PWM charge controller (Pulse Width Modulation). The PWM charge controller would compare the voltages and charge the battery to its need. The downside is that the delivered charge are in “bursts” signals, such as an on and off signal. This will by all means complete the job of charging and monitoring a battery, but this method is less optimal and can lead to inefficiency for such a variable factor like solar panel voltage..

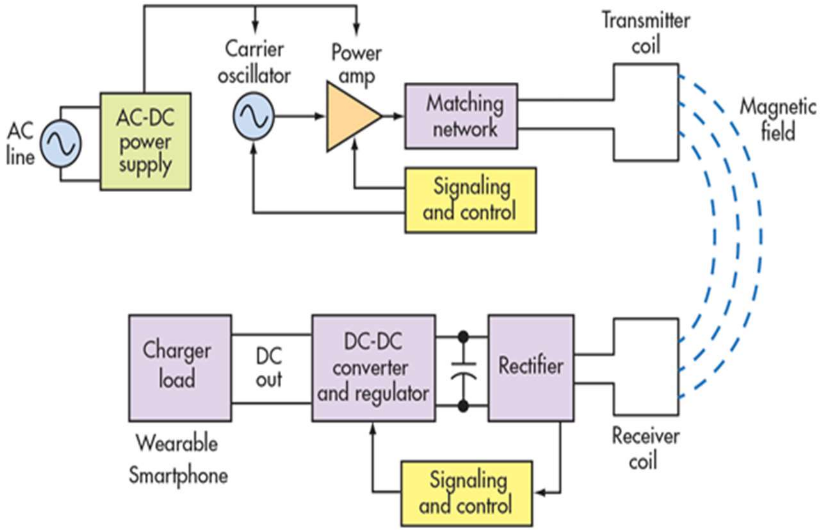
Since the eGOAT does not require a charging mechanism from our sponsor a charge controller for the battery is not required. A charge controller would only be useful for us if there was a power input for the battery to charge and would need a managing device. The charge controller is optimal for use when there is an input coming into the battery along with the load drawing power from it.

5.1.4. Wireless Charging

Wireless charging is an innovative way of charging a battery due to the fact that the battery and the source of power do not have to be in direct contact. Wireless charging for this project would bring a huge benefit , that being the ease of charging without taking into consideration a bad connection occuring. An example of this would be if the eGOAT needs to charge, it would just need to position itself under or over a “transmission pad” and being charging. This takes any mechanical positioning , or wire connections out of the situation. Alternating Current (AC) power source needs to be utilized in order to create a magnetic flux for a transmission coil. The magnetic flux would be dependent on the magnitude of the current and the number of turns and size of the transmission coil. The magnetic flux from the transmission coil would then effect the coil that transfers or distributes the power to a circuit that would then help charge a battery or power a load , in this instance a battery would be charged. When it comes to the market Qualcomm is developing Qualcomm Halo. Qualcomm Halo is a method to charge electric vehicles by just parking over a “transmission pad” in the ground. Uses along with electric vehicles are mobile device chargers. A diagram of how this system works is shown below in **figure 5.1**.

We have decided for the eGOAT not to involve wireless charging or any charging for that matter because of the functional requirements we are going to need to produce for the eGOAT. The eGOAT is not required by our sponsor to have a charging station or mechanism so we decided to save the budget by not involving one in the design.

Figure 5.1: Wireless Charging Diagram



5.1.5. Battery

In a normal primary cell battery the electrochemical reaction that takes place utilizes an anode ,cathode and an electrolyte. The electrolyte separates the anode and cathode and allows for the flow of electrical charge between the two. When a load is connected to a primary cell battery discharging takes place. The anode disperces electrons to the negative terminal and ions go to the electrolyte. At the positive terminal of the battery the cathode receives electrons which creates a flow of electrons and completes a circuit. Primary cells only work in one direction but rechargeable batteries allow for both directions of current. The main factors for deciding which battery to use for our project will be voltage rating, capacity, quality temperature thresholds and price.

A battery will be used in the eGOAT to support all its operation and will not be using any on system solar panels to support its operation during the day. A battery with high capacity will be critical in not limiting the eGOAT in its operation but also in any future systems and improvements. Considerations for battery come from looking at multiple sources that relate from batteries used in cars, trimmers and electric motorcycles. Car batteries are designed to supply high current for short burst in order to feed the starter and then start the engine. This means car batteries are less applicable for our project which needs to be able to handle continuous drain. The batteries that will be useful to our project then will be ones that are designed to be drawn from continuously such as electric cars/motorcycles and golf carts. **Table 5.1** is given as a reference for comparing these batteries.

Table 5.1: Battery Comparisons

Part number	Amp Hours (Ah) @ 20 Hr	Voltage	Length	Width	Height	Weight	Price	Vehicle
GC2-ECL-S	225	6	10 5/16	7 1/8	11	62	153.95	Golf Cart
2400S	251	6	10 1/4	7 1/8	11 7/8	71	192.95	Golf Cart
2300S	242	6	10 1/4	7 1/8	11 1/4	65	167.95	Golf Cart

Protection of our battery will be important due to the fact that there are so many environmental factors that could occur and damage components or introduce an unwanted signal along the system. Factors that can damage a battery such as overcharge, and over-discharge. Battery protection circuits will be a MOSFET centered design which would help connect and disconnect the battery from thresholds of overcharge and undercharge. For longevity purposes we do not want to stress the battery cells and preventing under and overcharge is crucial.

The long term goal in terms of our battery is to minimize battery replacement. Doing so will minimize the cost of operating and maintaining our project. The life of the battery will depend on factors like system load, ambient temperature during operation, and quality of the battery. We want to use a battery that can handle an infrequent drain due to the load stability and external factors. If a battery were to not perform to those specifications then the system’s components could operate at an undesired performance.

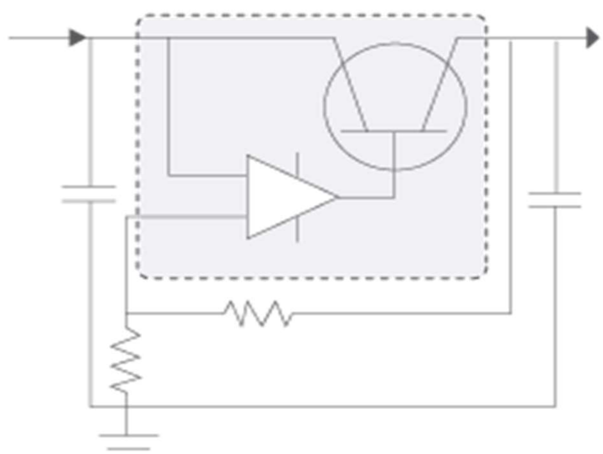
We have decided to use three batteries for the eGOAT two 12 volt batteries and one 18 volt battery. The batteries were selected on the criteria of: price, providing a minimum thirty minute run time, weight, and clean voltage and durability. The battery for the drive motors will be the Duracell Ultra 12V battery ($50), it has a capacity of 10AH which will be more than enough for the eGOAT to perform all the functions it needs in time. The electronics battery will be a Duracell Ultra 12V 5AH AGM ($33) , it has a capacity of 5AH and will be enough to power the electronics needed for the functions of the eGOAT: microcontroller , accelerometer , raspberrypi, and lidar. The trimmer motor battery will be the Ryobi P161, it is an 18 volt battery with a 2.5aH capacity for the trimmer motors ($90) to run for the duration of the operation time. The weights of all the batteries respectively are 6.6 lbs, 3.5 lb and 1.5lb for a total of 11.6 lb of total weight from the batteries for the eGOAT.

5.1.6. Voltage Regulators

There are many circuits that we have to use for power management , one of which is a voltage regulator. A voltage regulator regulates and manages the input voltage and output voltage of a circuit to manage the power. A voltage regulator circuit can be comprised of operational amplifier, transistors, capacitors and inductors. There a number of configurations needed to create a fixed , or continuously changing output. Instead of using all the components mentioned to create a regulating circuit , an integrated circuit can be utilized to keep footprint on printed circuit boards minimal. Instead of having a more complicated connection scheme on a PCB we can use an integrated circuit that utilizes 4 or 5 pins that can do all the work needed for desired operation. Two types of integrated circuits we can use are a switching regulator , and a linear regulator.

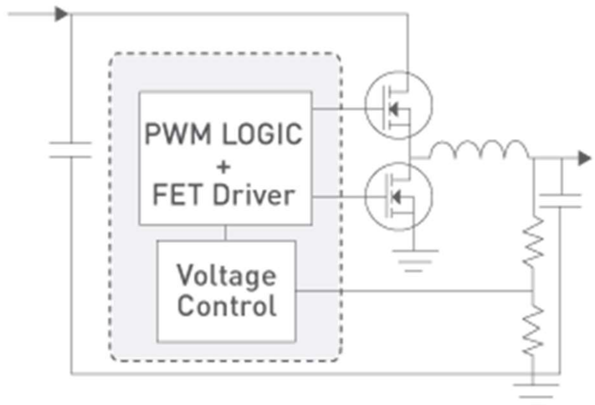
A linear regulator can be used when devices need low power and the difference between the input and output is small. The more difference between input and output the more power dissipation should be anticipated. Power dissipation can be calculated by by the difference of input and output multiplied by the load current. A linear regulator is usually used for stepping down a voltage , and its complexity is usually low. The functional model of a linear voltage regulator as seen in **figure 5.2** is an operational amplifier , a transistor , carefully selected resistance dividers schemes and capacitors for filtering input and output.

Figure 5.2: Linear Regulator



A switching regulator is a more complicated device that can be used in many more applications such as stepping down and stepping up voltages. Switching regulators have a larger range of input voltages so they are more versatile. The functional model of a switching regulator as seen in **figure 5.3** , has much more components to help create a controlled and stable output. The added cost for switching regulators are generally the external components to create a more stable output , they are usually capacitors, inductors and diodes.

Figure 5.3 Switching Regulator



For our design a switching voltage regulator will be utilized because of its versatility in stepping and stepping down voltages, and wide range of input voltages it can use. The LM2596 integrated circuit is a switching voltage regulator that can handle an input voltage of 4.5V to 40V. It provides overcurrent protection and will require several components external to it to function as a proper step-down: input and output capacitors, inductor, and a diode. Two versions of the IC will be used the LM2596SX-3.3/NOPB ($3) which creates a 3.3V output from the input range discussed earlier. In conjunction for our hardware design we will also be using the LM2596SX-5.0/NOPB ($5) which creates a 5V output for the design.

5.1.7. Estimating Load

Loads will be estimated on the power needed for each component. We should not neglect loss knowing that all the components we use will not be ideal. The largest loads will be the motors which will require a large battery to power them. The input required from the other concentrations will be factors such as: weight, height, speed, and stability. This all connects to what kind of components which will help us estimate the load needed.

The load view of how to model four electric motors connected to a battery will be is important. The electric motors can be viewed as an resistor and inductor (RL) branch because of the inductive nature of motors through the electromagnetic process to generate torque. A parallel configuration is needed to utilize the primary source of power for all motors.

5.2. Motors & Servos

Electric motors work using electromagnetic fields to create a torque. Torque is the rotational force that allows Current supplied from the battery is supplied into a commutator , which reverses the current through a loop or coil in the middle of two magnets. Directing the currents in opposite directions continuously creates a magnetic field which helps turn the coil. Since the two magnets South and North are engaging and disengaging with the magnetic fields it helps the coil turn. The difference with AC motors and DC motors comes from the fact that the alternating currents are changing direction in a periodic manner and does not need a component like a commutator. Incorporating different motors changes the project components. If dc motors are used the main power source will be a battery alone, but an ac motor would require an ac source which means added components such as an inverter. Selecting the right motors is important not just from an electrical standpoint but a mechanical view too. Motors are necessary for movement of our system and ask for a lot of thought when considering which kind. Factors are going to be voltage and current draw, power demand, rpm , torque rating, and temperature threshold.

The AI-assisted, autonomous solar powered rover-based robot to be designed for this challenge will likely use several types of motors in order to propel itself, articulate and drive string trimmer cutting heads, and deploy solar panels among other potential functions. Motor selection will be based upon affordability, availability, capability (torque and speed), and compatibility with other systems (interface with control and power systems, physical constraints, connection with body, transmission, wheels, etc.)

The motors used in this project will most likely be low voltage DC motors in the realm of approximately 12V-36V. This is primarily because batteries and solar panels output DC and the cost, weight, space, and efficiency cost required to run that through an inverter to an AC motor is prohibitive. To control power and speed of DC motors, motor controllers of an appropriate rating (voltage range, max current per channel; continuous, peak) must be used. Motor speed can be changed by altering the voltage, but that affects the motor’s power as well, and therefore motor controllers must vary motor speed through pulse width modulation; using the same voltage but pulsed at different frequencies. Speed and odometry can be measured with encoders, Hall Effect sensors, or other sensors that send a signal at certain points in the rotation of the motor.

Our design and selection of motors specifications will be based on the weight of the system the motors need to be able to support to move, and the amount of electric power capacity and load amount our power source has.

5.2.1. Drive Motors

The drive motors will be high torque and low speed in comparison to the robot's other motors. The propulsion motors will be controlled by localization and mapping algorithms running on the eGOAT's computer systems, and to aid in this it would be highly desirable for the drive motors to have highly precise position, speed, and odometry sensors (such as encoders or Hall Effect sensors) in order for the system to calculate robot movement and location. However, the eGOAT will have numerous navigation sensors, collecting sensor data from multiple sources in the environment in order to triangulate it's position and localize itself more accurately and reliably, so this is not an absolute must.

The angular position or speed sensors of the drive motors can be compared to each other to tell if the robot is turning or headed in a straight line, although we must account for inaccuracies due to traction loss and wheel slippage. This is most often done by statistically modeling the failure rate of all sensors (including the wheel encoders) and then combining them to create a statistical point map of the environment and the robots location in it.

The drive motors selected are two Lynxmotion 12V 90 rpm brushed dc gear motors. The motors come with hall sensor encoders for communication with our hardware controller to help understand the orientation of the motors at a certain point in time. The nominal voltage is 12V with a max current if stalling were to occur at 10A. These motors also include a 26.9:1 PG45 Gearbox for gear changing for different situations while moving.

5.2.2. Trimmer Motors

Some potential robot subsystems which could require motor actuation would be things like solar panels that fold out or movable arms to which the string trimmers are attached. The string trimmers themselves will need to be powered by high speed motors. It may be simplest to buy a trimmer and use the motor that comes with it in order to drive the string trimmer head, but it would be cheaper to separately buy the motors and string trimmer heads, then finding some way of putting them together. A separately purchased motor would have to be set to the correct speed so as to not throw off the automatic trim string feeding system. Motors can be paired with a variety of mechanisms like linear actuators for any number of movements, but it is obviously too early in the design process to begin planning for that, first it must be determined what is to move.

For the string trimming of the system an EC motor or electronically controlled motor would be most suitable. An EC motor is a brushless dc motor that is electronically communicated with to control speed and torque. Benefits of an EC motor are being brushless, power efficiency and are smaller in size. Being brushless means that the wear of the motor will be minimal , motors can use brushes to help switch currents to rotate. A brushless motor would mean the friction of the motors would not negligible. The power efficiency of EC motors stem from the fact that they are electronically controlled, there is no outlier movement and everything the motor does is being carefully controlled. EC motors do not depend on a specific power supply they can be controlled from the same power supply as other components just through an electronic circuit. An important feature of EC motors are they can provide a “ soft start” , lower noise when operating and lower temperature. A soft start is a gradual increase of voltage so nothing within the motor is damaged.

Since the trimmer will be an “off the shelf” component managing the assembly and configurations will be simpler. The rated voltages for the motors are around 18 to 24 volts and will need to be dismantled so the motor and trimmer are completely isolated for use.

5.3. Sensor Suite

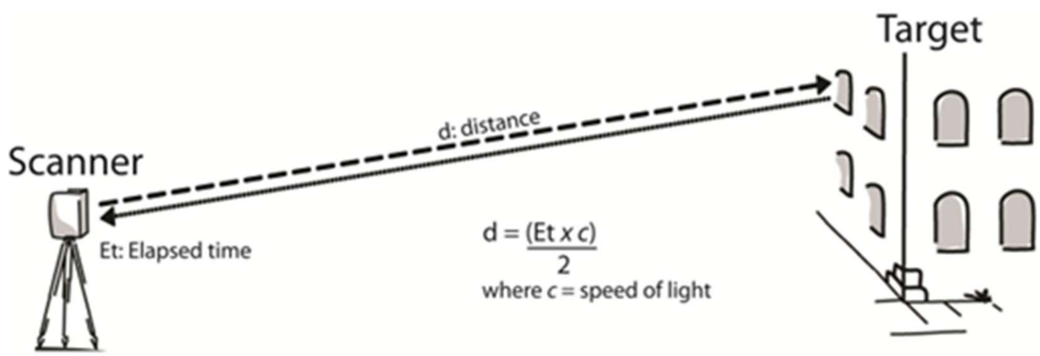
The eGOAT requires to have the ability to take information from its environment to be able to mow properly and efficiently. Using only one sensor would limit the eGOAT’s potential so multiple sensor were considered and how to best use them in conjunction with each other. To many sensors can be hurtful to design , by constraining voltage and board “real estate”, but many sensors help create a contingency correction for safety. It is important first to consider what the eGOAT requires to be capable of in its environment. The eGOAT is required to be able to navigate its environment so sensors are needed to be able to identify objects in their environment to prevent hitting existing infrastructure. The objective for the eGOAT is that it able to navigate its environment preferably without going over areas it has already cut and to not hit objects in its environments. The type of sensors that will be needed then will be able to differentiate whether grass has been cut and to identify objects in its environment to avoid, but still able to cut closely to it. Along with those main constraints some sensors will help with being able to determine whether the eGOAT can function in certain environments at all. Important considerations to take are that it is possible for the robot to be able to map its environment in order to avoid going over areas it has already cut. In this section we will be going over all sensors that will be useful to accomplish either of these task. In our test we are ignoring the possibility of a human on the field because there is an attached kill switch and button for someone to press when entering its vicinity.

The trimmer motors will be from the Ryobi 18-Volt Lithium-Ion Cordless String Trimmer which will be taken apart to use the motor that runs the trimmer. The off the shelf constraint OUC has told us makes this an excellent option to use.

5.3.1. Lidar

Lidar (Light Detection And Ranging) is a sensor that emits a laser and then detects the light as it reflects back to the unit from its environment depending on what hit it. Lidar has many uses but some of the most common seen are on autonomous vehicles, 3D mapping and to sample materials. The type of laser that is used with Lidar is dependent on the environment and what information it is trying to gain from scanning. The most common type of laser that is used with Lidar is infrared and has the wavelength between 1mm and 750nm. The information that can be gathered from using Lidar can range from topographic data to the speed of a moving object. The purpose of a Lidar used on the eGOAT will be to extract data that tells how far objects are in relation to the current position of the eGOAT. A Lidar can extrapolate the distance from objects in its environment using the time it takes for the laser to reflect back, the following is the equation for distance $d = (c * t)/2$,Where $c$is the speed of light t is the time of flight and d is distance. A figure showing how stationary lidar works can be seen in in **figure 5.4**.

Figure 5.4: How Lidar Works



This technology can be equipped onto the eGOAT to help identify objects such as racks that would support the solar panels in its intended environment. The eGOAT is considering two types of Lidar, one with a spinning base so that it is able to map its environment in all directions and stationary Lidar which will allow vision in a broader spectrum but only possible in one direction. The tables in the following two section list the types of Lidar available and some specifications that will be useful in determining which one would work best for the eGOAT. The following specifications are Range which is the actual distance the Lidar is able to pick up and retrieve data with a 75% reflective target. Additional testing will require to be done to understand the limits when not working with an reflective object and how adversely the sun can affect lidar. The refresh rate is how fast the Lidar is able to take scans per second. The power and current consumptions are important to take note because it can help estimate just how much power is required to operate Lidar when it is in active mode. The rotation frequency is how fast the Platform can spin per second which holds the Lidar. Degree of view is used in stationary lidar allowing it to see more then across one plane. The final choice for Lidar is dependent on the environment and the mechanical design of the eGOAT. The environment is dependent because the Lidar will be placed on top of the eGOAT and if everything is below it won't be able to help. The spinning Lidar will be useful for industry applications but the competitions could be different.

5.3.1.1. Stationary Lidar

A stationary Lidar does not rotate or move but has a divergence allowing it to scan across an area in one direction. This would be useful if we are only interested in the environment directly in front of it. The pros of this setup is that it allows to see more information about the environment in one direction. If a rotating Lidar is used it can only see what is on its path so things that are below the rotating Lidar will not be picked up. Additional benefits are that this type of Lidar has little to no moving parts which decreases or can eliminate any chance of error coming from mechanical parts. Less power will be required too if compared to its spinning counterpart. **Table 5.2** below shows a comparison of the available options.

Table 5.2: Stationary Lidar Specifications

Name	Range	Refresh Rate	Voltage	Current consumption	Degree of view	Cost
LeddarTech Platform Sensor Evaluation Kit	50m	1.5625 - 100 Hz	12VDC/ 24VDC		45°	$299.00
LIDAR-Lite 3 Laser Rangefinder High Performance	40m	1Khz	5Vdc	85mA	.5°	$149.99
Benewake TFMINI Micro LIDAR Module	12m	100Hz	5Vdc	800mA	2.3°	$39.00
LIDAR-Lite 3 Laser Rangefinder	40	1-500Hz	5Vdc	105mA	.5°	$129.99

5.3.1.2. Spinning Lidar

This type of Lidar still uses the same process as traditional Lidar with shooting out a pulsed laser but it is on a rotating base. The rotating base allows the Lidar to take visuals in 360° as long as it's the same axis. The possible choices for Lidar with spinning mount can be seen in **table 5.3**.

Table 5.3: Spinning Lidar Specifications

Name	Range	Refresh Rate	Voltag e	Rotation frequency	Current consumption	Cost
Sweep V1 360° laser scanner	40m (131 ft)	1075hz	5VDC	2-10hz	450mA	$349.0 0
RPLidar A1M8- 360 Degree laser scanner	12m (39 ft)	360 samples per scan	5VDC	1-10hz	450mA	$99.00
YDLidar G4 360° laser scanner	16m (5 ft)	9000hz	5VDC	5-12hz	480mA	$324.0 0
YDLidar X4 360° laser scanner	10m	5Khz		6-12hz		$109.0 0

The spinning Lidar that best meets our needs while still remaining affordable is the RPLidar A1M8- 360 Degree laser scanner. It is capable of a fast enough refresh rate and rotation frequency that will allow good measurements of the environment to be used in mapping. One negative of the RPLidar is that it has been discontinued which would make it hard to use for long term use as an industry solution. For this project that allows prototyping and testing though it will still meet all design required needs.

The Pulurobot M and its purpose is to be an autonomous mover that is capable of carrying heavy loads. It is supposed to be an application specific robot so it allows its user to actually configure its main mission or objective though. The Pulurobot M comes equipped with a Lidar,3D Time of flight cameras and sonars. Pulurobot M is designed to maximize Lidar visibility while still using a spinning base at a low height. The Lidar has been programmed to ignore the bases to allow it to see around itself. This design still allows for the Lidar to get measurements near the bottom of the robot. This is very attractive because the other option would be to put the Lidar on top of the eGOAT which would miss all objects in the environment that would be below the eGOAT.

Spinning Lidar has been chosen as sensor that will be equipped to the final design of the eGOAT. The YDLIDAR X4 ($109) will be used as our lidar sensor. ıIt features 360 degree scanning , anda 10 meter range. We selected it for its resistivity from external factors light, and its thin design. It has a maximum scan sampling frequency of 5Khz.

5.3.2. Inertial Navigation System

An Inertial Navigation system (INS) is a built in system that is used to determine the orientation and direction the system is currently facing using a process called dead reckoning. Dead reckoning is done by using past information of position and calculating the new location and orientation through estimates given by sensors over the passed time. Sensors that are used in an INS include accelerometers, gyroscopes and sometimes magnetometers. INS systems are attached to systems that need to have an understanding of how they are moving directionally. Common vehicles that use INS are ones where the pilot or driver can not easily understand how the vehicle is moving such as aircraft, submarines, ships, rockets and missiles.

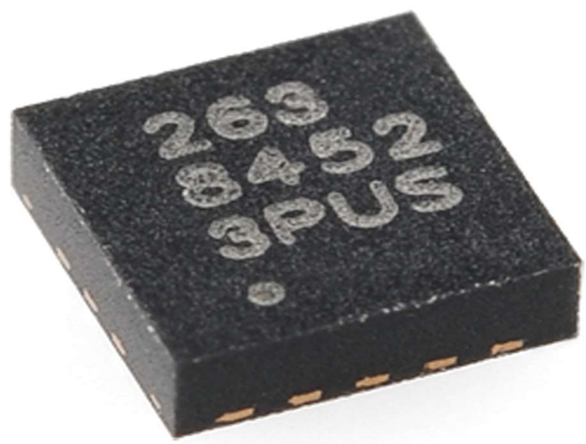
INS is used in today's Lidar surveillance equipment because as the Lidar is scanning the environment it is assigning geographic data to the point it just scanned so that it may be used in conjunction with existings maps and previous surveys. It is not necessary for the eGOAT to be able to assign geographic data as it is scanning its environment but it is necessary that the eGOAT has track of its position as it is moving and that it is communicating its position with the Lidars data. If INS is used in conjunction with Lidar it will better be able to track its environment accurately. For example as the eGOAT turns the Lidar which is making measurement of its environment can think there is a new objects that its is confusing with an old one. IDS can be used to communicate information about the current orientation and position to the eGOAT and let the Lidar know that the object it is currently scanning is still the same one it scanned earlier.

INS is not without its fault though because the sensors are not 100% accurate and INS uses previous measurements to find the new measurements. This means that the errors compound on top of each other and will build up. This means that the position needs to be periodically updated with another navigation system. In many airframes the inertial navigation systems include GPS and air data computers. Important considerations that will need to be validated in testing to see how accurate INS is on the eGOAT because sensors could have additional error from the vibrations caused from movement and the trimmers.

5.3.2.1. Electronic Accelerometers

An electric accelerometer is an electromechanical device that has the ability to measure both static and dynamic acceleration forces acting on it. A static acceleration is gravity itself and dynamic is the acceleration caused by movement. There are multiple methods for how accelerometers are made such as using the piezoelectric effect which is the ability of certain materials to be able to generate an electric charge in response to mechanical stress which the circuitry can decode to an actual value. The chip chosen for the eGOAT is the 3-axis MEMS(Micro-Electro-Mechanical Systems) Accelerometer which can be seen in **figure 5.5** below. No comparison was needed because the chip performed all functions needed at the low price of $2.95. The Accelerometer chosen can also be easily soldered on to our PCB to allow easy integration.

Figure 5.5: MEMS Accelerometer

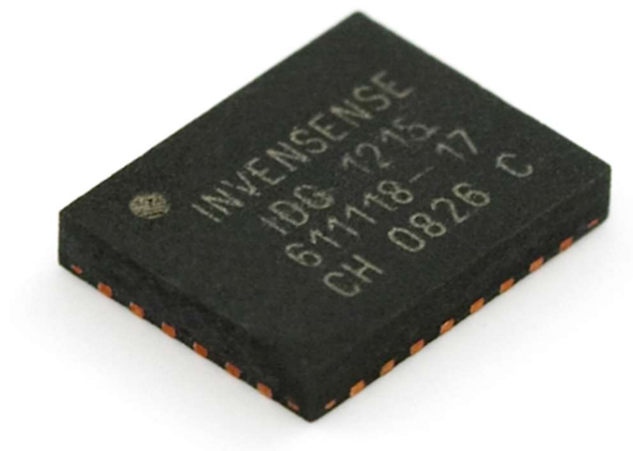


5.3.2.2. Electronic Gyroscopes

Gyroscopes give information relating to the device's orientation through measurements of its angular velocity. A gyroscope measures each individual axis's angular velocity by having a very small resonating mass that is shifted when the object is shifted and is able to translate these shifts to electrical signals that are then read by a host microcontroller. The gyroscope chosen for the eGOAT is the Invensense dual Axis Gyro, shown below in **figure 5.6**. No comparison was needed because the chip performed all functions needed at the low price of $2.95. The Accelerometer chosen can also be easily soldered on to our PCB to allow easy integration.

The accelerometer we have chosen is the MPU-6050. It is a gyroscope and accelerometer in one component. It has a digital output of I2C that will communicate with our hardware controller. The operating voltage supply is a range of 2.375 to 3.46 V with a logic supply of 1.8 give or take 5%.

Figure 5.6: Dual Axis Electronic Gyroscope



5.3.3. Close Collision Sensor

In case of failure of the main sensors that play a role in collision avoidance it is important to have a collision sensor that will help with both safety and protection of the equipment itself. A collision sensor will allow the eGOAT to have a protective measure that it has gotten too close to a crucial area it is trying to cut. This can be used in case it hits a person it will back up instead of trying to keep going forward. In its intended area there should be no structure that this robot should be able to push through so it is useful to have a collision sensor that will also help prevent the eGOAT from damaging itself by pushing against something in its environment. There is two possible sensor that can be used to act as a collision sensor which are a bumper sensor and a ultrasonic range finder. Both sensors are typically cheap sensors and will be easy to integrate into the design of the robot but both have their own distinct advantages and will still slightly affect the frontal design of the eGOAT.

5.3.3.1. Ultrasonic range finder

An ultrasonic range finder is a sensor that emits high frequency soundwaves that are undetectable to humans and waits for them to be reflected back by its environment to see if anything is near them. An example of how an ultrasonic range finder is used in vehicles today can be seen in Figure 5.14. The benefits of an ultrasonic range finder are that they help detect objects in front of it without hitting the object eliminating the chance of the eGOAT breaking something in the collision. This will allow the eGOAT not to require having a front bumper. If the string trimmers are placed in the front this will not hinder the radius of their cut when the eGOAT is operating. The possible disadvantages of this sensor is that the sound waves could be distorted from the motor and trimmer that will be used when the eGOAT is in use.

5.3.3.2. Bumper sensor

A bumper sensor is a simple sensor that works by completing a circuit connection when it bumps into something. After the circuit is complete it will send a signal to the processor letting it know it has made contact with some object in front of it. The benefits of a bumper are that is a simple circuit making it very reliable. One negative of this sensor means that is has to have contact and actually hit something though for it to operate, which could possibly damage some other portion of the eGOAT. This negative would be mostly negligible because the operating speed of the eGOAT would be at max speed 2 MPH.A bumper sensor sensor would be equipped to the front of the eGOAT and would be useful when the eGOAT is trying to cut around structure and due to some calculation error actually hits it letting the eGOAT it has gotten to close.

5.3.4. Fencing

An important consideration when designing the eGOAT is that how will it know where to cut in its environment. The eGOAT requires to be able to identify its boundaries and be able to stick to them for both safety and not waste its time cutting places that are not needed. Research from other autonomous grass cutters on the market actually use invisible fences and will be discussed as a possible course of action.

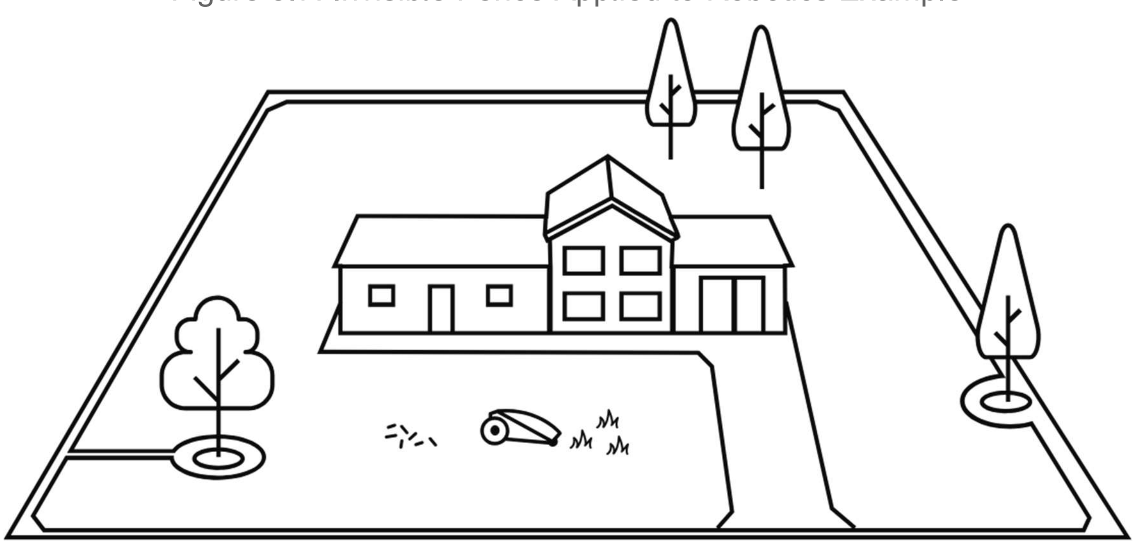
5.3.4.1. GPS fencing

GPS fencing also known as geofencing is a marketing strategy that actually pushes notifications to you that include deals in the local area. This technology could also be used in our robot to help configure a perimeter so that it does not mow area that is not in its functional environment. This technology operates by using GPS, IP address in building a virtual perimeter. It would be possible to create this same fence outside using only gps at a lower accuracy though.This technology can still be leveraged in order to prevent the robot from leaving the area it is supposed to function in. It would give additional benefits that it will not require any setup but will need able to access GPS services. It is possible to GPS service will not have to be active at all times. The eGOAT will not use the GPS service as part of its routine to mow so it is possible to only periodically access GPS services to verify that it is still in its functional boundary. GPS can remain active when it is near the boundaries and let it know that it should focus on cutting the grass in other areas.The eGOAT can also set the to sleep mode for a defined amount of time depending on how far way it is from the closest boundary using the information of how fast the eGOAT is. It is already necessary that the eGOAT is equipped with GPS so that it can send out a signal in case an accident happens and is not able to come back to its home base.

5.3.4.2. Invisible Fence

The invisible fence is a common technology that is used in both autonomous grass cutters and actually fencing dogs too. The fence is invisible to the eye because the key features of how the fence works are actually underground. A wire is placed underground and loops around the perimeter you want to make the boundary. Another good aid that can be seen in the picture is that if two wires are placed next to each other they actually cancel out each other signal so that the mower still know it can go over that area if it want it to avoid a certain spot. **Figure 5.7** below gives an example of an implementation of such a system.

Figure 5.7: Invisible Fence Applied to Robotics Example



5.3.5. GPS Tracking

Beacons are made for the purpose to track and locate someone or something and is possible with a variety of technologies. Beacons are used in multiple areas of industry to track and locate remote assets. GPS technologies are commonly used in vehicle tracking, Navigation and pet or child location tracking.

5.3.5.1. How Satellite Tracking Systems Work

Personal Locator Beacon (PLB) is a good example how location beacons are made and used. Most companies do not list how their satellite tracking services work so PLB will be used as an example. PLB is a common beacon used by campers, Hikers and anyone exploring the outdoors. A PLB is used by adventures when when they are stranded or in grave danger and self-rescue is no longer possible. A PLB works by sending out signals which are then picked up by satellites. The satellites are used by national help agencies where they can orchestrate a rescue. A PLB uses two signals one at 406MHz and a second at 121.5MHz. The 406 MHz signal can be located by satellites and can send rescuers within 5km of where the signal was sent. The 121.5 MHz signal is then used to help place the location of the sender and is accurate within 500M. A PLB is a useful reference because this method of tracking requires no internet connectivity and is effective in most areas and environments. A strong Battery is needed and used to output these signals.

5.3.5.2. Globalstar Satellite Transmitter

The Globalstar satellite transmitter is an efficient communication devices that is capable of sending one way data messages through Globalstar satellite service. The transmitter is capable of working in multiple modes and is able to be in sleep mode for the majority of its time where the power supplied is only 165 micro watts. Upon when it is needed when problems arise it can switch to transmit mode and send out coordinates and what is wrong. The Globalstar Satellite transmitter only requires 50 micro amps of current to operate in standby mode off with a 3.3 V input. This will means that the transmitter is ran off a lithium Ion metal battery with a 2.8 AH capacity it is capable of operating over a period of two years. The benefits of using a satellite transmitter are that there will be no limits on the range of the beacon. The possible negative is that Globalstar request a subscription service which will increase life-time and operating cost of using a satellite transmitter.

5.3.5.3. GPS through LoRa

LoRa stands for long range and is a digital wireless data communication protocol. LoRa is a proprietary technology that operates through radio frequency in the ranges of 169 MHz, 433 MHz and 915MHz. LoRa is comprised of two parts the network LoRaWAN (Longe Range Wide Area Network) and the LoRa PHY which is the protocol itself. The benefits of LoRa is that is capable of very high ranges which is implied in its name and has been documented to reach transmission ranges of 10 Km in rural areas. LoRa is popular in its capabilities in IoT where it allows easy communication at long ranges without the need for high cost.

LoRa would be used in the eGOAT's beacon system by sending out GPS information to a nearby facility or repeater that is capable of relaying this information where it needs to go which will allow a team to be sent out to retrieve and make any corrections needed. This is accomplished by attaching a LoRa tech transceiver that is capable of sending out information.The LoRa though does have a defined distance though so if for some reason the eGOAT leaves this region it will not be able to communicate back that it has been lost.

5.3.5.4. GPS Module Comparisons

Table 5.4: GPS Module Comparison Table

	Ublox Neo 6M	Skytraq S1315F	Skylab MT3329	Quectel L80	Ublox NEO M8N	RoyalTek REB-4216
Price	$13.28	$19.82	$21.10	$24.50	$25.28	$25.97
Update Rate (Hz)	5	40	10	10	10	1
Tracking Sensitivity (dBm)	-162	-165		-165	-167	-163
Cold-start Sensitivity (dBm)		-148		-148	-148	-148
GPS systems	Support SBAS (WAAS, EGNOS, MSAS, GAGAN)	Support GPS + QZSS + SBAS, QZSS, WAAS, MSAS, EGNOS, GAGAN	Capable of SBAS (WAAS, EGNOS, MSAS)	Support GPS, SBAS (including WAAS, EGNOS, MSAS, and GAGAN), QZSS, and AGPS	GNSS GPS, GLONASS, BeiDou, QZSS, SBAS and Galileo-ready1 WAAS, EGNOS and MSAS	Support GNSS GPS
Cold Start (s)	27	29	35	35	29	35
Hot Start (s)	1	1	2	1	1	1
Accuracy (m)	2.5	2.5	3	2.5	2.5	10
Supply Voltage (V)	3.6	3.6	3.6	5	3.6	3.3
Max Power (mA)	67	45		100	67	
Avg. Power (mA)	40	35	35	20	34	40
Channels	50	167	22 tracking, 66 acquisition	66 search, 22 simultaneous tracking	72	48 tracking
Misc	time pulse			data logging (LOCUS), time pulse	Odometer, datalogging, Differential GPS, TIMEPULSE	

5.3.6. Battery Temperature Sensor

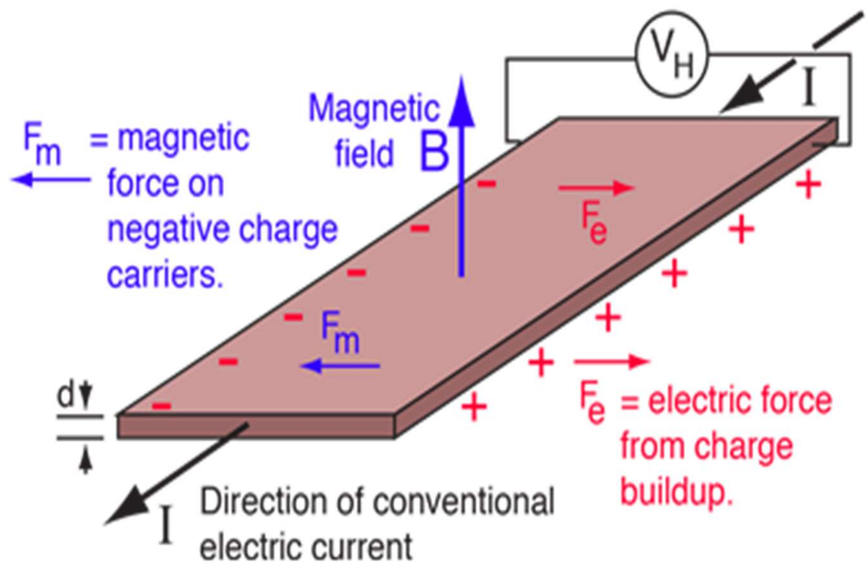
Due to environmental and load factors the battery of the eGOAT could be operating at a maximum load situation and be subjected to high temperatures.

This could lead to degradation of the system's battery, affect incoming and outcoming power and ultimately the quality of power. A Battery temperature sensor would help lower the voltage when the battery's temperature is to high, and increase the voltage when the temperature is low. The changes in voltages would be made through conditions written through us. It really is just a gauge for us to understand how the rest of the system's functions are affecting the battery condition. The temperature thresholds would be determined by the data sheet or recommendations of the battery maker.

5.3.7. Hall Effect Sensor

A hall effect sensor is a sensor that outputs a different voltage depending on the magnetic field it senses. Hall effect sensors can be used for various functions like switching positions, detecting velocity, and sensing currents. The sensor is a transducer which is a device that converts signals from energy it senses. The " Hall effect" is a physics phenomena: if a current is passing through a conductor in a significant magnetic field , the magnetic force pushes charges to one side of the conductor. The charges at the sides of the conductors will balance the magnetic field and create a voltage. This voltage that is measured is called the "Hall Effect". **Figure 5.8** shows an illustrated display of how the hall effect works. A hall effect sensor can output an analog or digital output depending if it is being used for an operational amplifier or a microchip. The hall effect could be used for the eGOAT when it comes to getting closer to objects that are "out of bounds. It would need to measure magnetic fields to do this so a device that transmits such fields would need to be placed at the out of bounds area. The hall effect sensor itself is just a thin strip of metal with an electric current connected to it. These sensors are used in dc motors to detect the position of specific parts like the rotor. This then helps adjust electrical components supplying to the motor to adjust. Pricing for hall effect sensors are usually at a low cost maximum , about $5. There will be hall sensors on the drive motors discussed earlier. The hall sensors use the same technology and will help with the orientation of the motors at a given point in time.

Figure 5.8: Hall Effect Sensor



5.4. Communications

There are several different protocols that could be used for this project, each having their advantages and disadvantages. Several will be discussed later. Different types of communication protocols have widely varying use cases. Some require high amounts of data to be transferred between different devices, be they a single unit and a tower that handles multiple connections, like GSM (2G/3G), or 4G internet. This type of system is useful in that it has good range and is scalable to handle thousands of concurrent devices, but it comes at a considerable cost. It takes modern phone companies to run these resources effectively, as it takes a central owner to maintain and operate the tower systems. On top of that, the power consumption rates are too great for small-scale devices that are expected to operate for extended periods without requiring charging.

Other technologies have use cases requiring extreme range, such as Long-Range Wi-Fi. This is a modified version of standard 802.11n Wi-Fi that in essence uses larger and more antennas directionally instead of omni-directionally like home Wi-Fi routers. This too, requires a tower or some sort of platform to mount the transmitter on to ensure that the signals, which have a hard time passing through solid objects, can get the best range. Work has been done to show that this is viable for several hundred kilometers with staggering bandwidth.

Lastly, other technologies such as Bluetooth focus mainly on low power requirements, for use with close-range small capacity devices. These are mostly seen in peripheral devices to phones and computers for streaming small amounts of data. This is the opposite end of the spectrum compared to GSM. What this project requires is both long range and low power consumption, or the best of both worlds. That is where LoRa comes into play. LoRa offers several kilometer device-to-device communication. The amount of data shared is small but is still sufficient for real-time interfacing with individual eGOAT units if it can be utilized effectively. The main communication that this step of the project is concerned with is sending simple commands, such as the remote kill command, and getting simple diagnostic data from the device.

5.4.1. Wi-Fi Communications

Wi-Fi communications covers a wide range of communications protocols underneath the umbrella of the IEEE 802.11 standard (e.g. IEEE 802.11a, IEEE 802.11b, IEEE 802.11n, etc.). Discussing all the variations of Wi-Fi and their potential applications is beyond the scope or length of this document, however for our purposes they can be grouped into two categories based on application: local communication and long range communication.

5.4.1.1. Local Wi-Fi Communications

Local communications is probably the most widely recognized and used utility of Wi-Fi, and it is increasingly common in modern systems for even inexpensive computer and microcontrollers to come with a built-in Wi-Fi module capable implementing anything up to an IEEE 802.11ac connection. Wi-Fi of this sort would be useful for local diagnostics and testing, since it would be possible for anyone nearby with an access code and a laptop to connect up with an eGOAT unit. Additionally, because both the onboard computer and the hardware controller would likely have Wi-Fi modules, either could be used to create a local network. It would also be possible to combine them into a single network so information from either subsystem could be shared easily both within the local network and without.

Advantages

- Extremely cheap (free or <$10)
- Extremely high data rate (depends on hardware)
- Moderate power usage (<1A)

Disadvantages

- Limited range (<10m)

5.4.1.2. Long Range Wi-Fi Communications

Long Range Wi-Fi is a specialized adaptation of the standard 802.11n Wi-Fi protocol built for extreme ranges. Mostly what this involves is using more antennas on a typical access point to extend the range and capability. More equipment means greater power draw, and for a typical low-cost antenna (~$25) the power requirements were around 10 amps. This is likely not a good option for the eGOAT given our size and power constraints, as can be easily illustrated by **figure 5.9**.

Figure 5.9: Long Range Wi-Fi Amplifier Example (used as part of the public domain)

Advantages

- Moderately expensive (~$25)
- Extremely long range (~300km)
- High data rate (up to 170 Mbps)

Disadvantages

- Large size
- Must be mounted high on the unit for good connection
- Very high current draw (~10A)

5.4.2. Bluetooth Communications

Bluetooth is a wireless transfer protocol used for small, low powered peripheral devices. Despite being cheap, common, and small, it has extremely small effective range. This limited range alone will severely impact its utility in this product.

Advantages

- Extremely cheap (<$10)
- Low power consumption (<500mA)
- Small form factor
- Easy installation and pairing
- Commonly used by many peripherals

Disadvantages

- Extremely limited range (<3m)
- Low data rate
- Unreliable in certain conditions

5.4.3. Mobile Internet (2G/3G)

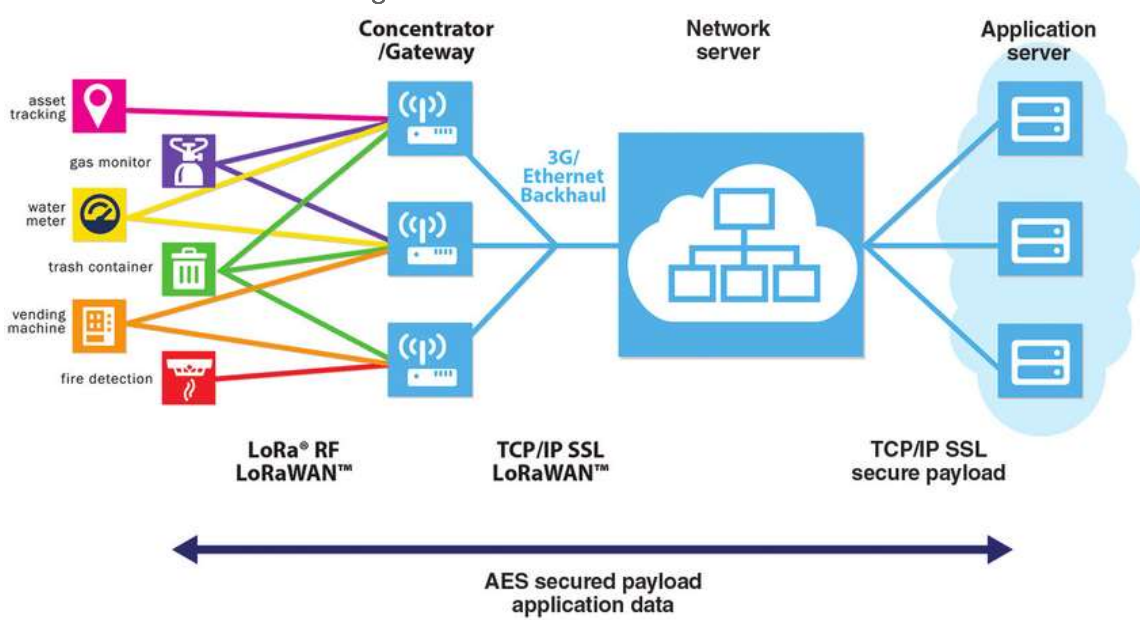
Global System for Mobile communications (GSM) is the standard used by cellular phones. The network requires a base tower that clients connect to and handles the routing of data to other clients. Although this communication method is very common and powerful, it requires infrastructure that the eGOAT will not be guaranteed access to. Further, although a diagnostics or remote control system over the internet via this method is certainly possible, it is far too cumbersome given the design needs of the eGOAT to justify using Mobile Internet in this capacity, and for device-to-device communication this project requires a more streamlined communications stack.

5.4.4. LoRa Communications

We could use either Wi-Fi or Bluetooth for short range connectivity, however currently we lack longer range protocol for field deployments where infrastructure and access to a secondary network are lacking. One option is something called LoRa (meaning Long Range communication). LoRa is a low power, low data rate, long range protocol, capable of keeping a connection over miles with very little power (30mA receive, 100mA transmitting). There are a few different frequencies that we can use including 433mhz or 915mhz, both of which can be used in the US.

It has been demonstrated that it is possible to build a versatile, long-range network on top of LoRa called LoRaWAN, which allows several LoRa devices to connect to a single gateway, which is another device designed to handle multiple signals. Typically, this device will have greater capabilities than any individual LoRa equipped device and will be responsible for different tasks. These could include connecting to a transmitting data to a web server API. A current widely used network is call The Things Network, which advertises a network built on just LoRa. It eliminates the need for mobile or wi-fi connections by building a robust, well connected network of LoRa devices. Such a system could also be implemented for the eGOAT and its base station and potentially other eGOAT units to form as low-power, long-range network that allows extremely versatile communications and coordination. **Figure 5.10** below illustrates how such a network might be constructed.

Figure 5.10: LoRaWan Network



Advantages

- Cost effective (<$20)
- Great range (>1km)
- Low power consumption (<100mA)

Disadvantages

- Not very common, requires specialized module and interfacing
- Low data rate (<50Kbps)
- High bandwidth variance relative to max data rate depending on conditions

5.5. Computational Hardware

The computational requirements of the eGOAT are twofold: first a central “main brain” computer that has most of the processing power, and second an array of lesser computation hardware that is slaved to the central computer. In order to be an attractive solution to the landscaping needs of our sponsors, the eGOAT must be able to perform its function in a variety non-standard locales that were not designed with its use in mind with as little installation and spool-up time as possible. Essentially, the system must be capable of operating generally and effectively in any number non-engineered environments with little or no pre-existing information.

This fact, along with the large number of potential obstacles and wide-ranging set of possible tasks the eGOAT must perform, will require the implementation of some kind of simultaneous localization and mapping (SLAM) algorithm, as well as the algorithms to handle navigation; sensor filtering and synthesizing; and short-term and long-term task planning just to name a few. The relatively large processing power and multitasking required by these algorithms necessitates the inclusion of a reasonably powerful computer with an operating system and graphics processing in order to coordinate the various functionalities and subsystems of the eGOAT as well as interpret the data feed from the sensor suite and servos in the amount of time available.

However, the inclusion of an operating system as well as the amount of processing it is responsible for also means that we can not depend on this central computer to always operate in real-time. Therefore, we must include some computation hardware that we can rely on to control those critical subsystems and functions that absolutely must operate correctly in real time. These smaller subsystem controllers will be slaved and bussed directly to the main computer to handle a large assortment of task, including: accept higher level directives from the main brain, expand upon those directives to deliver commands to low-level hardware systems, receive and cache feedback from sensors and servos, and respond to those emergent inputs that require an immediate response for the safety of humans or the system itself. These controllers will also be responsible for monitoring the internal hardware status performance of the subsystems and will be capable of immediately shutting down these subsystems and notifying the main computer in the case that continued operation would endanger the system's integrity in some way, such as electrical surge or malfunction, mechanical failure, loss of sensor input, or other erroneous behavior.

These problems are commonly faced by robotics enthusiasts, RC hobbyists, drone pilots, university research teams, and professionals alike. As such, there is a breadth of knowledge available from these sources that we have drawn from as well as a wide variety of technologies to choose from. In this section we research and examine the variety of options available to us, comparing the pros and cons of each technology or product.

5.5.1. Single Board Computers

Single board computers (SBCs) represent an interesting option for our main computer system, as most modern examples offer respectable computational power, reasonably powerful onboard graphics processing, generally high cost efficiency, and the huge variety of systems on the market allow for a wide range of performance profiles, price points, and power consumption. In general, SBCs tend to be smaller, more reliable, lighter, cheaper (when comparing overall per-unit system cost), more energy efficient, and more convenient in terms of form factor when compared to more common multi-board computers (MBCs) of similar capabilities. Given the eGOAT's necessarily restricted size and power availability, these qualities make SBCs an attractive option for use in the eGOAT project.

Despite the fact that he overall classification has existed for decades and have remained popular choices for a variety of purposes throughout, especially for embedded applications, they have been remained a relatively niche technology until recently. It wasn't until the advent of affordable mobile computing technologies (such as ARM) and the subsequent explosion in demand for such products that the economics of scale began to benefit SBCs in the same way it MBCs. Because of this, SBCs have become a favorite among hobbyists and researchers on projects ranging from DIY "smart" applications to robotics. This is perhaps the most attractive feature of SBCs: there is an enormous body of knowledge to learn from and utilize on a vast array hardware and software designed around interoperability and ease of integration. The **table 5.5** below is provided as an overview of the discussed SBCs' specifications.

Table 5.5: SBC Comparison Table

SBC	Raspberry PI 3B+	Libre Computer ROC-RK3328-CC Renegade	ODROID-XU4	Asus Tinker Board S	PINE64 ROCKPro64
Cost	$35	$40-$80	$80	$85	$60-$80
CPU	64-bit Quad Cortex-A53@1.4GHz	64-bit Quad Cortex-A53@1.4GHz	32-bit Quad Cortex-A15@2.0GHz & Quad Cortex-A7@1.4GHz	32-bit Quad Cortex-A17@1.8GHz	64-bit Quad Cortex-A53@1.5GHz & Dual Cortex-A72@2.0GHz
GPU	VideoCore 4	Mali-450 MP2	Mali-T628 MP6	Mali-T760	Mali-T864
Memory	1GB LPDDR2 SDRAM	1, 2, or 4 GB DDR4 SDRAM	2 GB LPDDR3 SDRAM	2 GB LPDDR3 SDRAM	2, 4 GB Dual Channel LPDDR4
Ports	4 USB 2.0 ports	2 USB 2.0 1 USB 3.0	1 USB 2.0 2 USB 3.0	4 USB 2.0 ports	2 USB 2.0 ports 1 USB 3.0 type A 1 USB 3.0 type C
GPIO	40-pin header "RPi"	40-pin header "RPi"	30-pin & 12-pin headers (2.0mm, 1.8V)*	40-pin header "RPi"	40-pin header "RPi"
Power	5V/2.5A DC via MicroUSB	5V/2.5A DC via MicroUSB	5V/4A DC via Barrel Plug	5V/3A DC via MicroUSB	12V/3A or 5A via 5.5mm Barrel Plug

5.5.1.1. Raspberry Pi 3 B+

System Specifications

- **Cost:** $35
- **Processor:** 64-bit Cortex-A53 (ARMv8) Quad-Core @ 1.4GHz
- **Graphics:** On-Board VideoCore 4
- **Memory:** 1GB LPDDR2 SDRAM
- **Storage:** MicroSD for OS Image, Supports USB Storage
- **Wireless:** Integrated Dual-Band WiFi & Bluetooth LE
- **Ports:** 4 USB 2.0

- **GPIO:** RPi Style 3.3-5V,2.4mm 40-pin Header w/ SPI/I2C Support
- **Power:** 5V/2.5A DC via MicroUSB

Although the current popularity of the SBCs among hobbyists is the result of a great number of factors, the release of the original Raspberry Pi 1 Model B in 2012 by the Raspberry Pi Foundation is where this paradigm shift truly came to a head. Since then the Raspberry Pi Foundation has continued to nurture and grow one of the most vibrant and well supported technical communities around. The knowledge base available for implementing any model of the Raspberry Pi in a huge variety of applications completely dwarfs that of any number of SBCs, and the number of well-documented, open source solutions available (to both robotics specifically and technical issues in general) is truly staggering. In fact, the Raspberry Pi form factor, hardware compatibility/interoperability, and performance profile has become something of a standard and benchmark in this field, and the Raspberry Pi Model 3 B+ that was recently released offer respectable performance at a one of the lowest price points available.

That being said, the original purpose of the Raspberry Pi 3 B+ as an inexpensive educational tool for developing nations begins to show in more demanding applications like ours. There are some examples of the Raspberry Pi 3 B+ being used in both SLAM and computer vision applications, however those examples are either far more limited in scope or use proprietary (likely highly optimized) software. Despite the Raspberry Pi 3 B+ being extremely cost effective, from our position it is questionable if fitting all of the software we would need onto one is even feasible, and the technical challenges of operating two of them in synchronously are significant.

5.5.1.2. Libre Computer ROC-RK3328-CC “Renegade”

System Specifications

- **Cost:** $40-$80, depending on memory size
- **Processor:** 64-bit Cortex-A53 (ARMv8) Quad-Core @ 1.4GHz
- **Graphics:** On-Board ARM Mali-450 MP2
- **Memory:** 1, 2, or 4GB DDR4 SDRAM
- **Storage:** MicroSD for OS Image, Supports USB Storage
- **Wireless:** No Integrated Support, USB Dongle Only
- **Ports:** 2 USB 2.0 & 1 USB 3.0
- **GPIO:** RPi Style 40-pin Header
- **Power:** 5V/2.5A DC via MicroUSB

The ROC-RK3328-CC “Renegade” was released by the Libre Computer Project in January 2018 and is intended as a complete drop-in upgrade to the Raspberry Pi 3 B+. Sporting the exact same form factor as the Raspberry Pi 3 B+ (minus one USB port) and equipped with upgraded USB 3.0, choice of 1, 2, or 4GB DDR4 RAM (as opposed to the only 1GB of DDR2 RAM on the Raspberry Pi 3 B+), a significantly more powerful graphics coprocessor, and an identical processor, the ROC-RK3329-CC largely succeeds in this goal. Additionally, because the ROC-RK3328-CC had such a focus on interoperability with the Raspberry Pi 3 B+ when it was designed, it also has many of the same drivers and hardware interfaces, and the specifications as well as research that we've been able to turn up lead us to believe that many of the same software and hardware modules designed around the Raspberry Pi 3 B+ will work with a minimum of hassle on the ROC-RK3328-CC.

That being said, ROC-RK3328-CC has not yet become a very popular project board yet and the Libre Computer Project has not been able to build up a large, active community like the Raspberry Pi Foundation has. Subsequently, the number of well-documented projects using the ROC-RK3328-CC that we have been able to find is limited, and even fewer of those projects demonstrate its interoperability with the Raspberry Pi 3 B+. Further, despite the significant of the technical gains seen in the ROC-RK3329-CC, it does not improve on the performance profile of the Raspberry Pi 3 B+ in many of the areas that we were most concerned with. Although the relatively limited memory of the Raspberry Pi 3 B+ was a concern, and the upgrade to DDR4 RAM would certainly improve the system's overall speed, it is still questionable if the unchanged processor would be sufficient for the eGOAT's needs. Finally, at a cost of $80, the cost efficiency of the ROC-RK3328-CC is not very impressive compared to many of the option available.

5.5.1.3. ODROID-XU4

Computer Specifications

- **Cost:** $80
- **Processor:** 32-bit Cortex-A15Quad@2GHz+ Cortex-A7Quad@1.4GHz
- **Graphics:** On-Board Mali-T628 MP6
- **Memory:** 2GB LPDDR3 SDRAM
- **Storage:** MicroSD or eMMC for OS Image, Supports USB Storage
- **Wireless:** No Integrated Support, USB Dongle Only
- **Ports:** 1 USB 2.0 & 2 USB 3.0
- **GPIO:** 1.8V, 2.0mm pitch 30-pin & 12-pin Headers
- **Power:** 5V/4A DC via Barrel Plug

Since its release, the ODROID-XU4 has garnered a reputation among SBC users as an extremely fast alternative to the Raspberry Pi, being equipped with the powerful Samsung 32-bit Exynos-5422 octa-core processor and on-board Mali-T628 MP6 graphics coprocessor along with 2GB of DDR3 RAM and support for booting off an eMMC chip for faster startup times. The manufacturer of the ODROID-XU4 also provides the SBC with very comprehensive support, offering wide variety of documentation, hardware add-ons and accessories, and official software support for Ubuntu 16.04, Ubuntu 18.04, and related drivers. Although no where near the size of the Raspberry Pi community, this combination of the ODROID-XU4's power, cost-efficiency, and manufacturer support has resulted in a fairly large and active community. From this community, we have been able to find a number of detailed projects, tutorials, and debugging guides that would be very helpful in making use of the ODROID-XU4 in the eGOAT, although there is a limited amount of information on its use in robotics specifically.

Despite how highly recommended the ODROID-XU4 generally is, there are still some issues that may come up. For one, the ODROID-XU4's high performance in such a small package leads to issues with heat generation. This heating issue is so bad that the standard ODROID-XU4 board ships with a pre-installed heatsink and air cooling fan, and even with this additions there are still some reports of performance loss due to overheating in an *indoor* environment. Perhaps even more of a concern is the ODROID-XU4's hardware interoperability, despite largely conforming to the form-factor of the Raspberry Pi 3 B+, it does not conform to the de-facto standard set by the 40-pin GPIO header of the Raspberry Pi 3 B+. Where the Raspberry Pi 3 B+ header uses pins rated for 3.3V to 5V and a pitch of 2.4mm, the ODROID-XU4's 30- and 12-pin headers have a pitch of 2.0mm and are only rated for 1.8V. Because this standard is so much less common many peripherals that would be easy to plug-and-play with on the Raspberry Pi 3 B+ would be difficult to integrate at best or unusable at worst. The manufacturer of the ODROID-XU4 does sell a board that converts the GPIO pins to the RPi standard, but this is less efficient in in terms of power and signal latency, takes up more space, exacerbates the ODROID-XU4's heating issues, and costs a significant percentage of the board itself.

5.5.1.4. Conclusion

We ultimately decided to use the Raspberry Pi 3 Model B+ as the main onboard computer for the eGOAT. Although its hardware specifications are comparatively weaker than the other options we considered, its ease of integration and huge knowledge base are too powerful of a tool to pass up on. In order to make up for the deficit in performance, the team has elected to make use of a graphics coprocessor.

5.5.2. Graphics Coprocessor: Movidius Neural Compute Stick

Graphics coprocessors are a relatively recent entry into the SBC technology market. They represent a powerful tool for applying SBCs in computer vision and graphics roles, but there is really only one option with a significant track record in real applications: Intel's Movidius Neural Compute Stick. The Movidius not actually a graphics processor at all, it is an integrated visual processing unit (VPU) that is optimized for running a wide variety of pre-trained computer vision deep neural networks. It is intended to be used in field deployment settings and because of its easy compatibility with many computer vision algorithms it can essentially be treated as a GPU for our purposes.

Specifications:

- Cost: $80
- Processor: Intel® Movidius Myriad X Vision Processing Unit (VPU)
- Supported frameworks: TensorFlow and Caffe
- Connectivity: USB 3.0 Type-A
- Dimensions: 72.5 mm x 27 mm x 14 mm
- Operating temperature: 0° C to 40° C

5.5.3. Hardware Controller

The hardware controller will be used to control all motors and monitor critical safety sensors in real time. Although the onboard computer is also capable of performing these tasks, we considered it a significant safety concern to depend on the onboard computer to respond to emergency signals in real time given that it will already be running the Linux OS, computer vision software, and SLAM algorithms. The requirements and decision for the hardware controller were passed on by the CS team, who ultimately decided to use the Espressif ESP32-WROOM-32D.

5.5.3.1. Espressif ESP32-WROOM-32D

Specifications:

- **Cost:** $10
- **CPU:** Xtensa LX6 microprocessor
- **Memory:** 520 KB SRAM
- **Storage:** 16MB internal flash
- **GPIO:** 34 physical GPIO pads

5.6. Safety

Safety is a key point in all of engineering because as soon as injures arise it not only means the harm of people but also a lost of reliability in not only the product but also the company. As the eGOAT operates on solar farm grounds it is imperative that safety parameters are increased and functions to fully operated for the eGOAT , because of the important infrastructure on the farm.

Along with the infrastructure are the legal and financial ramifications that can arise if an employee is hurt on the job at the solar farm.In the house of quality we have listed safety as being the most important customer need and have designed the robot to ensure that carries through. This is accomplished by discussing and giving the eGOAT multiple means to prevent harm and damage to its environment in case of failure on the sensors that are attached.

5.6.1. eGOAT's Presentation

Making sure the presentation of the project is acceptable is important but making sure the presentation is safe is much more vital. We want to make sure that all wires are secured and any conductors are insulated properly. Making sure that short circuits will not happen is imperative for all components and safety for total system. We will make sure that all components are secured onto the frame of the system so that nothing dangerous falls off or harms people around the eGOAT.

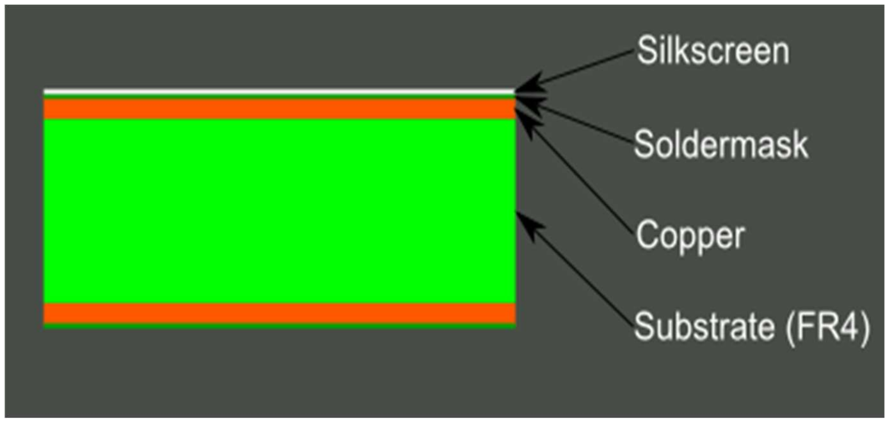
5.6.2. PCB Design and Considerations

A Printed Circuit Board (PCB) is a board that electrically connected components using conductive tracking through the use of copper laminated sheets in order to supply power through a system. PCB is the most common way to connect electrical equipment in today's market because it is cheaper and production is able to be automated. PCB's can require additional design then compared to past techniques such as wire wrapping but current Computer Aided Design (CAD) software can help offset the additional work. A pcb is created by a layer or layers of copper tracks that are laminated onto sheets of insulating sheets. The copper tracks can have multiple layers in order to allow more connections in a smaller area. The connections can not cross so multiple layers can prevent the circuit being short circuited. The two most common way in mounting components to a PCB is through "Surface Mounting" and "Through Hole". Through hole components are mounted by first passing wires through the board where they are then soldered and the tips above the soldered can be clipped. Surface mounting is done by attaching the leads directly to the copper traces on the board. Both these techniques can be implemented on a PCB at the same time and are use for particular components. Surface mounting is commonly used for smaller components like resistors, diodes and through hole is traditionally used for larger components such as large capacitors.

5.6.2.1. PCB Composition

PCB are comprised of multiple layers, There is 4 distinct layers when looking at the composition of a single copper layer and they are stacked on top of each other like a cake. Starting from the top layer to the center is the silkscreen, Soldermask, Copper and the substrate. An visual of the order of composition of a PCB can be seen in **figure 5.11**. There are multiple layers to a PCB but they are still very thin, for example the common thickness of a PCB for an arduino is only 1.6mm.

Figure 5.11: PCB composition order



Substrate

The Substrate of a PCB is the base material used at its center. The Substrate is important because it does not only provide the strength of the material but also controls its dielectric constant and how fire retardant the material is. A very common substrate that is used is FR-4 which “FR” actually stand for flame retardant. FR-4 is a glass-reinforced epoxy laminate that is popular because of its capabilities that allow it to be used in multiple environments. FR-4 has a good strength to weight ratio and is capable of being used in both mechanical and electrical applications in both humid and dry environments. The capabilities of FR-4 make it a good consideration to be used on the eGOAT as its substrate due to its flexibility to be used in most environments.

Copper

The copper layer is used to actual make the connections between components and is able to come in multiple layers, it is possible to have 16 or more layers. The copper layer is laminated to the board through the application of heat and adhesive. In lower cost electronic gadgets it is common to see the PCB have only only one layer and when double sided is mention in PCB’s it means it is a 2-layered board. The amount of layers need is dependent on the how many connections are being made in a set amount of real estate on the board. The amount copper that is traditionally used in a PCB is 1 ounce per sqft on a PCB but is possible to raise that higher if the board is being designed for high power applications.

Soldermask

The Solder Mask is layer above the copper foil and is traditionally colored green but it is possible for it to be multiple colors. The purpose of the Solder Mask is to insulate the connections of the copper when solder is being applied. The mask prevents accidental connections with other metals and helps solder correct points. The mask does not cover up the small traces where components are supposed to be surface mounted.

Silkscreen

The silkscreen is the very top layer of a PCB and is used to help the locations of the components on a PCB. The labels allow for easier setup when soldering the material and an easier understanding of the board. Common applications of a silkscreens can be seen on developmental boards that label multiple inputs and outputs such as buttons and LEDs.

5.6.2.2. PCB Design Software

PCB design software is an Electronic Design Automation (EDA) software that allows for developments of PCB through an array of tools. The first thing needed to start a PCB design though is still a completed schematic of the design with all proper connections. After the schematic is finished and all parts are chosen it is possible to download libraries of the component chosen and start building the schematic in the EDA software. This is needed now because with the components chosen it will let the board know the dimensions needed for connections.

There are multiple good PCB EDA software out there and a few that will be examined to be used to design the eGOAT's PCB are EasyEDA, Eagle, Orcad and Protel. It is important to note that Eagle and Orcad both have free versions that have limited capability. When choosing a software to use it is important to identify what is most important to the programmer. The most import criteria to our team is its intuitiveness, useful features, robust library, well established and lastly the community. Eagle has been selected for this project because of it large community also because if additional functionality is needed it is only 100$ for a year subscription of eagle. Eagle will give not only additional resource but also flexibility to the eGOAT.

6. System Design

Our system design comprises of the the hardware and software design complementing each other. Our hardware design provides our software components with all it needs to perform so it is totally functional. The software design also does the same with helping control hardware when needed to provide overall safety , control and functionality of the eGOAT. The overall system has been designed to enable the following features: Safety, Efficiency, Control, and functionality. The system design is not constricted to assisting the components we selected but also the computer science and mechanical team's required components. The requirements our system design achieves will be: communication of components, powering components, creating structure stability , and creating efficient space management for the "real estate" of the eGOAT.

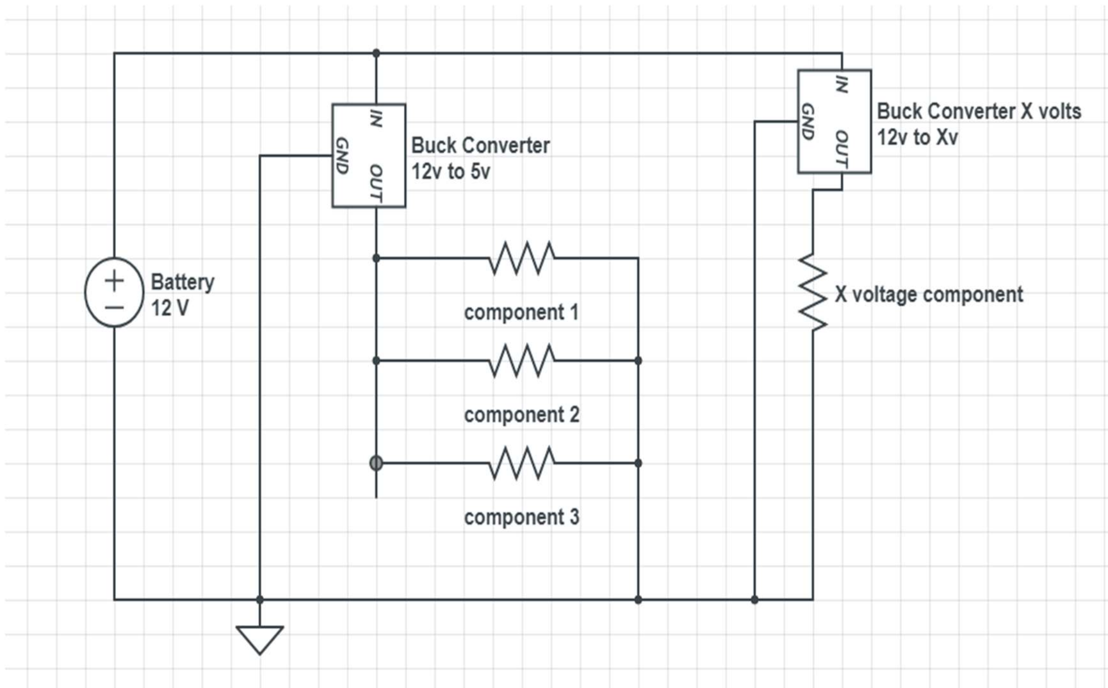
6.1. Hardware Design

Our hardware design is a made up of power management components, power sources, controllers and electronics to be powered. The components selected are for the best operation of our system. Our design stemmed from the fact that components that the other engineering teams needed components to be powered and communicated with. These would be the raspberry pi , lidar system , motor controllers and motors. The components we chose to help power and communicate will be batteries , buck converters, microcontroller chip and motor controllers. We chose not to use solar system because for space to keep it on board of our system and also the effectiveness of the amount of charge and performance it would hold for us. The power distribution and management will be delivered in a printed circuit board.

6.1.1. Power Management Design

One of the major decisions is how to power the the electronic components in a simple design for the printed circuit board. Many of the sensors and processors operate at a lower voltage than the battery that will supply the power. This causes us to utilize a device that can "step-down" the voltage for the components. The voltages required to power the components are DC so a special circuit will be needed to lower the voltage. Using a buck converter would help us lower our input voltage which would be 12 volts from our battery and step it down to 5 volts which is needed for a majority of our components. This would help create a voltage bus where we can connect all our components in a parallel from the bus as seen in **figure 6.1**. For other components that need a different voltage we would add a parallel branch that would have the battery voltage across it and from that 12 volt node add a buck converter to step down to "X" volts needed for any components.

Figure 6.1 Power Distribution view point



6.1.2. Voltage Regulator Design

There were a number of regulating circuits we could use for stepping down the voltage from our power source. We knew that we needed deliver a voltage of 5 volts with a current of .5 and about 1.5 amps of current to two devices. We also knew our microcontroller circuit needed a 3.3 volt supply as well along with our accelerometer we are using. Since we knew we were stepping down voltage we needed an efficient device to perform this power management operation. Our power source could be as high as we wanted but the more the difference from the power source voltage and the output voltages are the more loss and inefficiency we could create. We decided that an input voltage of 7 volts to 12 volts would be a range of operation for our power source and we needed to design a buck converter that could perform the proper step down through the whole range of input voltages. This also helps us create options for the battery when we select according to capacity and price.

The integrated circuit (IC) we will be using is the LM2596 which is a “3A Step-Down Voltage Regulator” The LM2596 has adjustable output voltages of 3.3, 5 and 12 Volts from an unregulated voltage input up to 40 volts. For our design we created our regulator to have a range of 7 volts to 12 volts. The reason for that range is that if the voltage of the battery were to lower for any reason we would still have the desired outputs we need, and this was created for our power reliability part of the design. The two versions we will be using LM2596SX-5.0/NOPB (5V) and LM2596SX-3.3/NOPB (3.3). This integrated circuit uses a series of operational amplifiers, feedback loops and transistor switches that help create the output needed with the help external components like capacitors and inductors. Instead of creating a step down module for our pcb via operation amplifiers , transistors and limiting resistors we decided to use the LM2596 IC for the functionality and simplicity for our design. The functional diagram for this IC includes a thermal limit block that allows for protection of current from both sides of the IC which will help with the safety and life of the voltage input which is the battery. The LM2596 is important for our design because it helps create “step down” needed for a regulated stable voltage for the components we need to power. This IC has 5 pins , a Vin , output, ground , feedback , and On/Off pin. Vin,output, and ground are obvious pin terms, respectively they are the voltage input, the output of the circuit and the grounding of the circuit. The Feedback pin is one that helps understand that the output is the regulated voltage and helps communicate back to the IC. The On/Off pin has a function of switching off the regulator, to enable this feature a voltage of 1.3 v and above will need to be connected to this pin. We have no intention of turning off the regulator so this pin will be grounded which keeps the IC on as you can see in **figure 6.2**. In our design if the regulator was to turn off the components we would not have any power flowing to them. The two regulators will be sharing the power source of the battery the two inputs for the both circuits are 12 volts, creating a parallel connection. The LM2596 also has an over current protection and over temperature protection which is very important knowing that our battery needs protection from any faults that may occur.

There are two versions of this circuit we will be using , 5 and 3.3 regulated voltage. This will help convert our 12 volt battery voltage into the desired voltage for our microcontroller (3.3v) and the raspberry pi (5v) for the computer science team. Along with the raspberry pi , the lidar system component we will be using will also be powered by the our pcb on the 5 volt line created for the raspberry pi. Testing of this IC has been done through the buck boost circuit that was bought. Since a pcb should not be adjustable at the voltage regulation level the tested circuit and our schematics for the pcb differ because the tested circuit is useful for all outputs, where our is fitted for an exact output. The PCB layouts as seen in **figure 6.3** and **figure 6.4** designed on eagle are small in their footprint and will have surface mount components in place of the components seen in the schematics.

For the 5 volt regulation we designed a 2.5 A max output, because the rated max output for the raspberry pi is 2.5 A , with consultation from the computer science team the 2.5 A will most likely not be drawn from the raspberry pi and given that measure we decided to add a branch from the 5 Volt node to power the lidar system which draws a max current of 480 mA, for reassurance that the raspberry pi does not reset managing all vital and integral components for the computer science team. The components selected to accompany the lm2596 5v version were carefully calculated to give our desired output. The C_in is the input capacitor on the input power supply side of the IC. It is used to prevent heavy voltage transients and needs to have proper RMS current rating because of the high currents that the capacitor will exhibit. Avoiding transient currents on the input side of the integrated circuit is vital because it protects the battery we will be using. The input capacitor rating is 39uF with a 1.25 A RMS ripple current rating. The output capacitor was selected to assist in filtering the signal and give stability to the output. We used a 4.7uF capacitor with an impedance of 1.4 ohms which helps create a low ripple current at the output. The inductor we selected was to create a continuous mode of operation which can offer a better output. When the IC is in continuous mode the inductor can create sawtooth waveforms that would be DC output load current as an average. We are using a 33uH inductor that correlated with the suggested chart in the data sheet for the LM2596. A schottky diode was utilized to help create a “return path for the inductor current when the switch turns off”. This diode is known as a “catch diode”:it is responsible for We needed a fast diode , a common diode was IN5400 being used but it is too slow for our desired operation. We are using a forward voltage diode of 320mV to help obtain our desired output. These are all the components needed for the 12 to 5 volt buck converter for our pcb design. Using this 5 volt IC has a lot of advantages and one we focused on for our design was the efficiency. The efficiency is listed to be about 80% and that is very important for our design because of the importance it holds for the whole time of operation.

In our design we need a seperate 12 to 3.3 v step down for our ESP 32 microcontroller and accelerometer as seen in **figure 6.2** . The pin layout is the same for the 5 V buck converter with 12 volts being supplied , and the on/off switch will be grounded.The components around the LM2596 3.3 version we selected for our design are: the input capacitor being 100uF with an impedance of .024 ohms. The output capacitor which is used for filtering the output signal will be 4.7uF. We chose a 33uH inductor and a schottky diode with a forward voltage of 950mV. The same decisions for these components were modeled off the 5v buck converter components around the 5 volt version of the LM2596.

Figure 6.2 12 to 5v step down

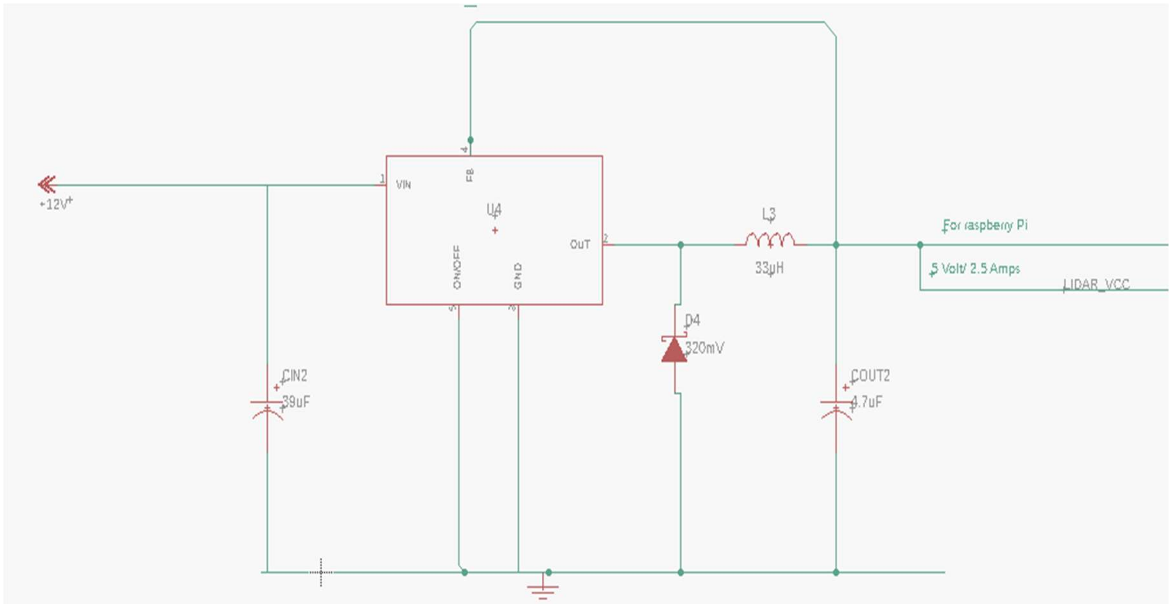


Figure 6.2 12 to 3.3 V step down

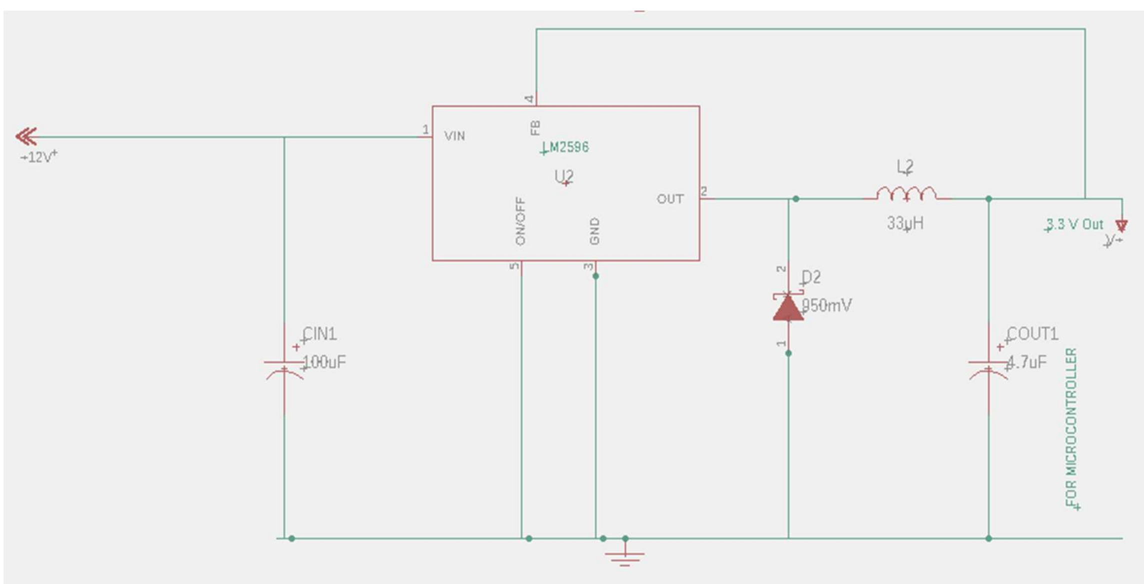


Figure 6.3 12 to 5v buck converter PCB

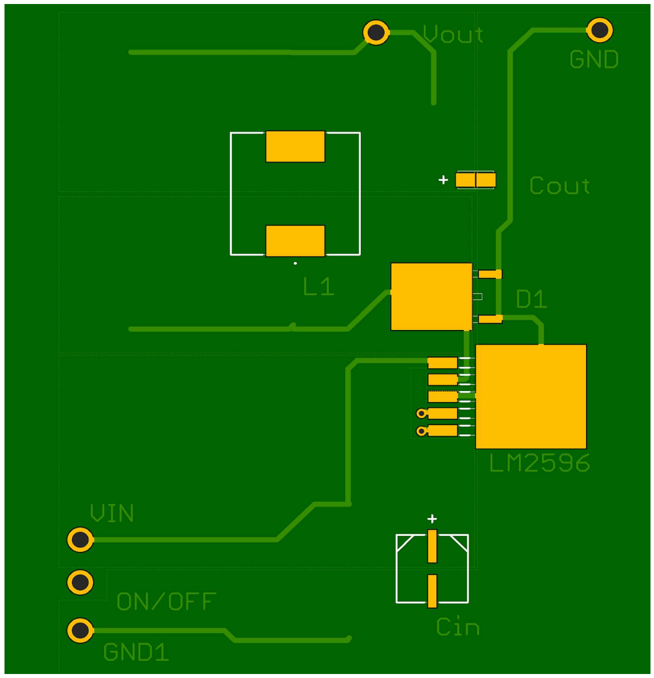
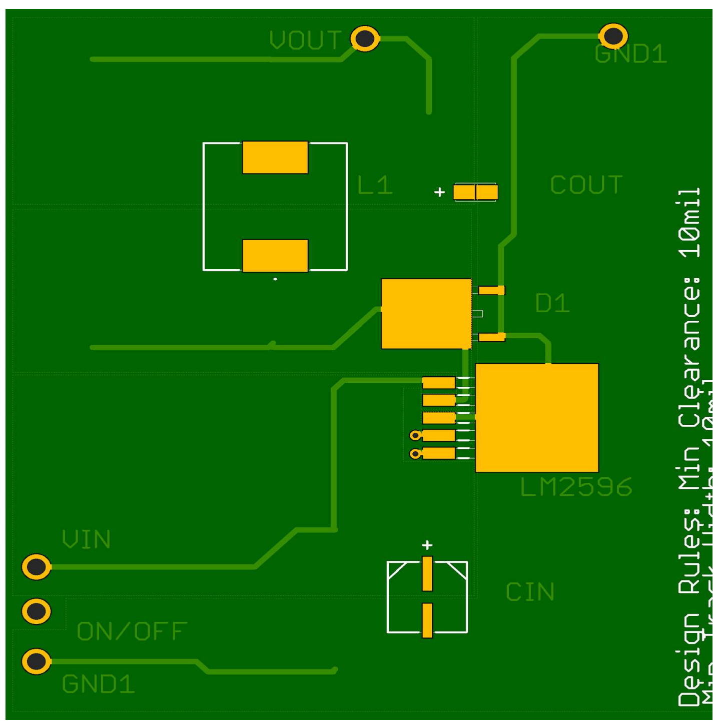


Figure 6.4 12 to 3.3V converter PCB

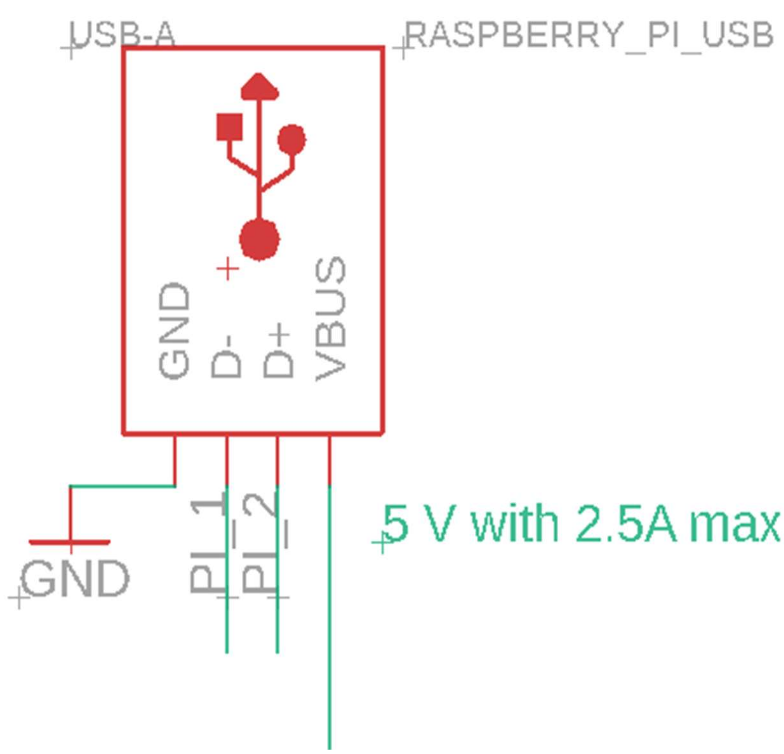


6.1.3. Power Output Design

There are four external devices that will be connected to the PCB: Raspberry Pi, Lidar, Drive motor controller, and the trimmer motor controller. To make our PCB more accessible and easy to manage we needed a simple way of powering and connecting them. Connecting components to the pcb is as important as supplying the voltages at the output terminals. If the connections are the wrong length and inefficient then we can see voltage drops,and current drops over the connection thus creating undesired results for powering our components. The connections, wires or cables can be seen as essentially resistors in the way of the power output terminal and the component needing power.

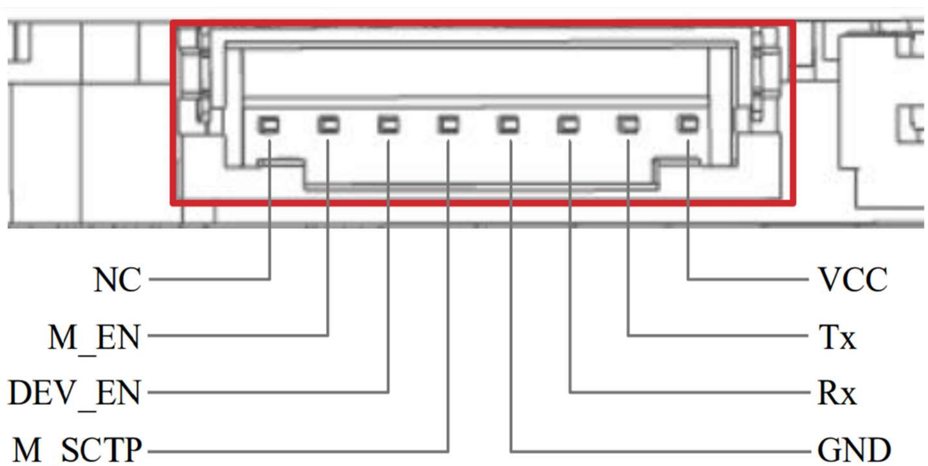
The raspberry pi will be connected through a USB port that transmits not only power but also data. The eGOAT's functional design depends on the raspberry pi and the ESP32 communcitcating. As seen in the **figure 6.5** a USB port has 4 pins: ground, data+, data- , power. The data+ and data- ports will be connected to the PI_1 and PI_2 pins that are located on the ESP32. A usb port can handle a 5 volts which is exactly the amount of voltage the raspberry pi needs to operate. The data pins will be connected to the ESP32 which is a means of communication. The physical connection of the PCB and raspberry pi computer will be connected via Micro usb cable.

Figure 6.5 USB for Raspberry Pi



The lidar component for the eGOAT demands a voltage of 5 volts, but needs to be communicating with the raspberry pi. Our PCB does not need to have any communication with the lidar component but will supply the power to it. The reason being the raspberry pi may not be able to accommodate the current draw the lidar may require. The Lidar has a unique pin connection that plugs into it to help it operate correctly. The Lidar selected by the computer science team has a pin layout that has data connections , along with a ground and VCC pin as seen in **figure 6.6** below. Our design is to have a wire soldered to the pcb header for the lidar voltage and then connected at a junction of the connector cable for the lidar to power the pin needed for VCC. The other connections for the pins will have their source running from the raspberry pi computer.

Figure 6.6 Lidar Connection port



The motor controller ports on the PCB will be data connections and will require ports that can connect wires to create a communication between the ESP32 and the motor controllers. These will be soldered on to the headers of the PCB that correlate with the data pins of the esp32 for communication.

6.1.4. Motor Control

The motor controllers selected will be external of the pcb because of the fact that they are not pcb acceptable but will be connected via data line from the esp32. The motors need a very steady voltage source so a seperate battery to power the motors through the controllers will be utilized.It is best to not run the current through our pcb because of the high current draw that can occur. We chose not to because current will be high and fluctuating and can impart a transient response back to our main battery.

The motor controller for the drive motors and trimmer motors will be the Cytron MDD10A. The MDD10A allows for two motors to be controlled so this ideal knowing that we have two drive motors that need to be in sync for proper operation. It has an input of 5 pins: Ground, Pwm1, Pwm2, DIR1, DIR2. The PWM pins are the input speed for both the designated motors, which would be connected to ESP32. The DIR or direction input pins would also be data lines connected to ESP32. The MDD10A also has a terminal block for the motors and power of 6 Pins: Motor outputs for 1 and 2, and the Power terminals of the battery, The reason for the MDD10A is for the simplicity of two motor accessibility and control. The drive motors selected are brushed DC gear motors with an operating nominal voltage of 12 Volts. The drive motors have an encoder connector that helps connect the positive and negative terminals of the motor. There are 6 pin connections on the drive motors: Positive, Negative , Ground, Hall sensor VCC, Hall sensor A Vout and Hall sensor B Vout. The Hall sensor Vout pins will be connected to the ESP32. The hall effect sensors will help the ESP 32 understand how the motors are oriented in a rotational sense.

To control the trimmer motors we will be using the same type of controller , the Cytron MDD10A. The motor controller for the trimmer motors will have the same functionality as the drive motors. The only pin that may not be used is the DIR pin or direction pin. There would be no need to change the direction of the trimmer motors (clock or counterclockwise) because they are just tools that will be continuously running and performing lawn cutting. The trimmer motors have not been selected yet because of our mechanical team’s decision timing. We have been assured that our motor controller for the trimmers will be able to operate the voltage of the trimmer motors. The MDD10A has a voltage operation range of 5 to 30 volts, which is large range to select trimmer motors.

6.1.5. Battery Design

Our design comprises of 3 batteries one for 12 volt battery for the PCB components , one 12 Volt Battery for the drive motors , and one 18 volt battery for the trimmer motors. Three different batteries are important for our design for many reasons. We wanted a seperate battery for the PCB components so that they have a stable power source that will not be interrupted or damaged by transient voltage feedback from motors. That leads us to the next reason for a battery for the motors. The motors can draw up to 10 Amps and that can be detrimental to operation of our components if the battery was shared with the computers and the motors. For safety of our components we thought it was important for two seperate batteries to run two seperate systems. The trimmer motor battery* will be separate as well knowing that it has to be a different voltage. The reason we decided not to use a step up from a 12 volt source was the instability it can create and the nature of the motors which can create transient current to run through the system. The trimmer motors have not been selected in time for us due to the mechanical team’s decision timing. The only concrete information we had received was that the motors would be 18 volt due to off the shelf ratings of trimmer motors.

The selection of our batteries stated in our research page are as two duracell ultra 12 volt batteries (10ah and 5ah) and one ryobi P161 18 volt battery with 2aH.The selection of our battery follows a design equation seen below. Knowing the supply will be 12 volts for our PCB, the current being drawn out of the power supply will be multiplied by the voltage to give us the total power being used. This will allow us to understand how much capacity we need for the pcb. The same procedure will be used for the motor batteries which can draw more current at different times.

V - Battery Voltage, *I* - PCB current draw , *T* - operation time (hours), *X* - total watt hours , *C* - battery capacity (amp-hours)

$V * I = P; P * T = X; \quad X \div V = C$

Along with the electrical aspects of our design , the three batteries help the mechanical design of the eGOAT. The weight of the batteries help create a stable weight distribution for the structure and stability of it. The eGOAT should not be able to easily be flipped over so the added weight helps with the moment of inertia for it to move in a more efficient and robust manner.

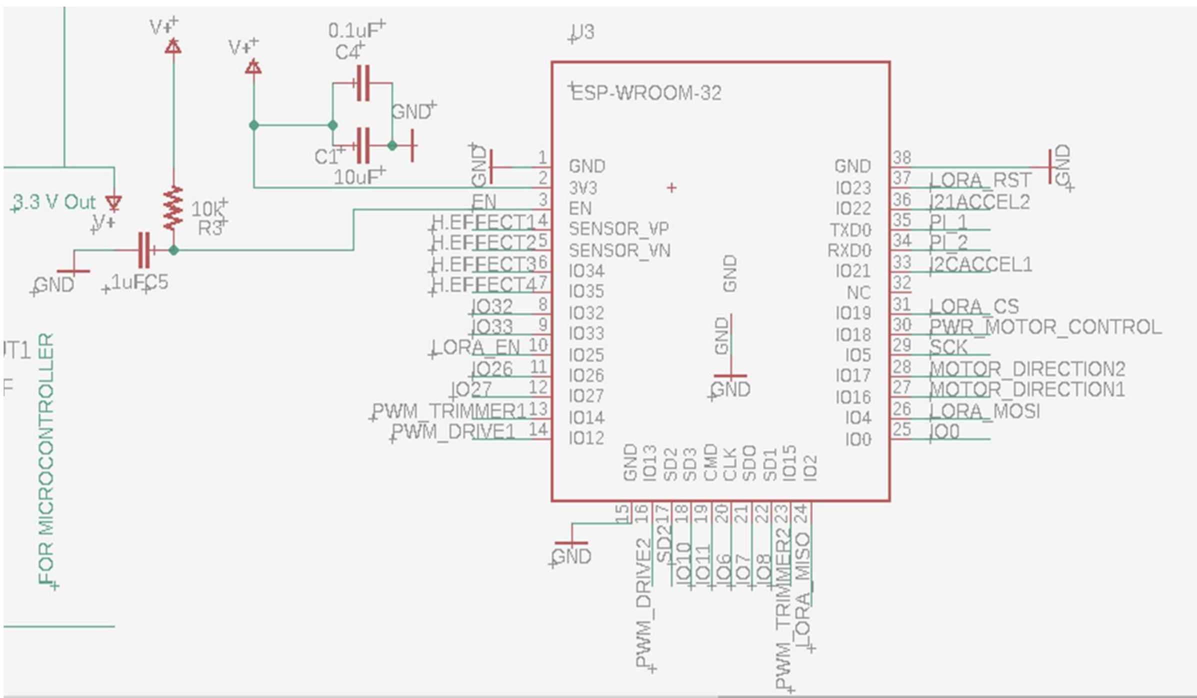
6.1.6. Microcontroller PCB design

For the PCB layout for the microcontroller section it will be a through hole layout for the purposes of development. When the microcontroller is written with all the software needed the actual microchip will be inserted into the through hole layout to finally be connected and operate on the pcb.

The microcontroller we will be using will be the ESP32. It will be connected to our 3.3V power line that helps power it and enable one pin vital for its functionality. As seen in **figure 6.7** the 3V3 pins requires a 3.3 voltage source to power the esp32. For the 3V3 pin the 3.3V source is connected but in conjunction to that line are .1uF and 10uF capacitors in parallel. The .1uF capacitor is for filtering the 3.3V signal. This ensures a safe voltage entering the esp for its functionality. The 10uF capacitor is used for reserving power incase of increases in voltage demand. The EN pin on the microcontroller requires a voltage but lower current so a 10k resistor is connected in series to the 3.3V supply. The 0.1uF capacitor is connected for filtering the signal for the EN pin so it does not receive a signal that could “confuse” its functionality by enabling it and disabling it continuously.

The ESP32 will have a number of data outputs connected to it for major components of the whole system which will include: Motor controller data, hall effect sensor data, raspberry pi communication and accelerometer data communication. As seen in **figure 6.7** below there a set number of pins that correspond to different communication interfaces, including UART, I2C, and SPI. These pins will be allocated to the right component connection and will send a voltage signal that acts as a binary signal for certain components. The jumpersfor the components will the terminals where the connections take place.

Figure 6.7 ESP32 PCB schematic



6.1.7. Summary of Hardware Design

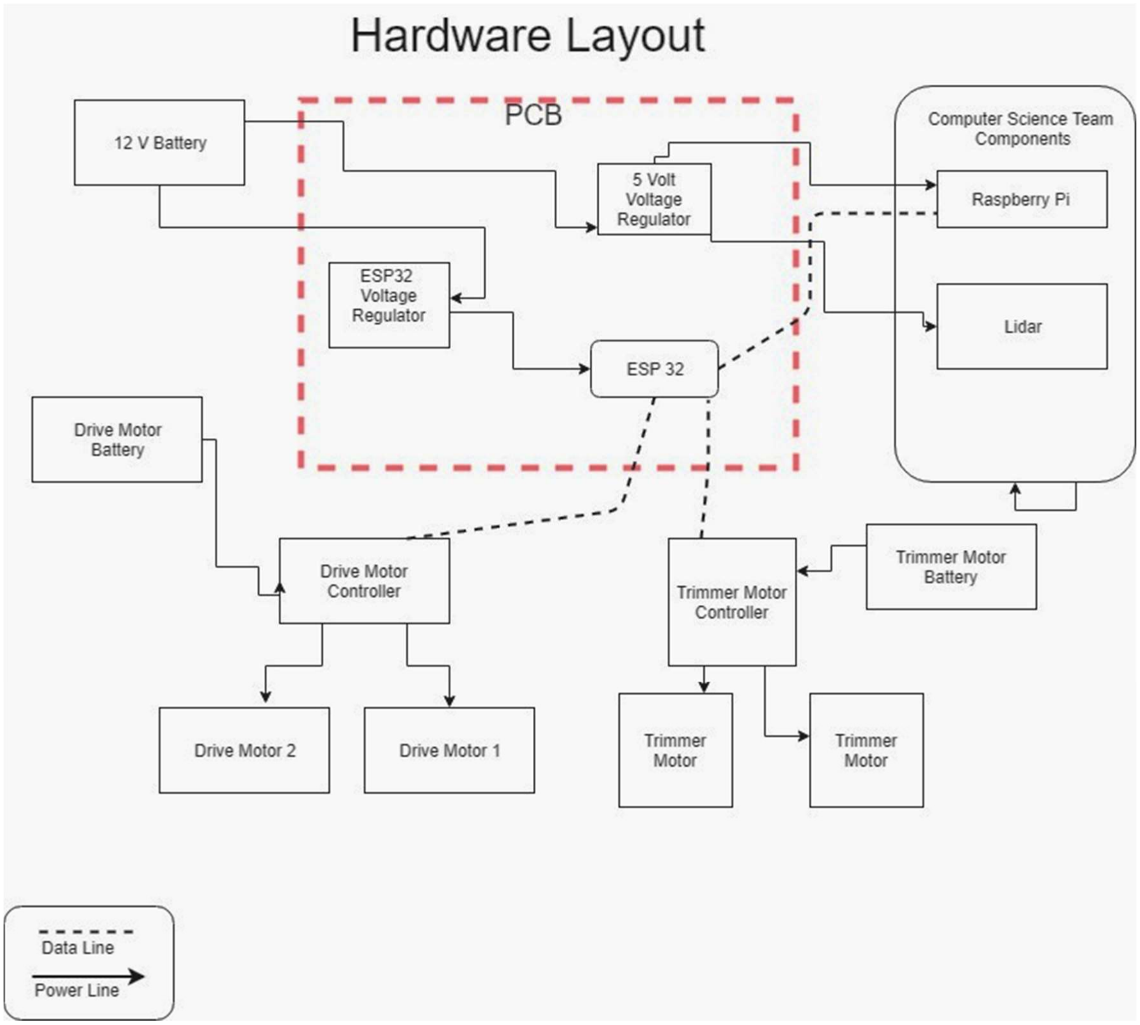
The hardware design as seen in **figure 6.8** for the eGOAT consists of batteries, controllers and voltage regulators. The biggest design task was to design a voltage regulator or "buck converter" to help step down the voltage of the battery to the components that need lower voltage. This helps minimizes the battery selection process and design: instead of using seperate 5 volt and 3.3 volt batteries we designed our pcb powering system to use one 12 volt battery and distribute the voltage through a step down. The reason we did not want to "step-up" voltage is because we are essentially "creating energy" and this can be very inefficient and lead to problems like overheating our power sources, and connections to fulfil this operation. One positive attribute of our step down design is that the 12 volt battery will have more capacity than two separate batteries. This ensures that the one power source will be drained in sync with the current draws of all the hardware electronics needing power from it. If two batteries were utilized they would need to have the same capacity and need to discharge at the same rate which would not be very easy to accomplish.

The PCB we created will be a power management source along with the home of the microcontroller ESP32 we are using. It is the main hub for all the electronics that need to have substantial power delivered to them and communication. Our design is focused around reliability , efficiency and a small footprint in the overall design of the eGOAT. We believe that a smaller PCB that can incorporate everything essential for powering the eGOAT's main electronics is a big positive. It saves on space, weight and overall management of the system. When it comes to manipulation of space to attach our pcb on board the system there should be no issue knowing it is a small size.

The motor controllers selected have to be external to the pcb. The reason being is the best suited controllers for our drive motors and trimmer motors are very complex and work best with the motors selected by the mechanical team. This is also due to the “off the shelf” factor: a requirement by our sponsors to use off the shelf trimmers and motors. Our design ensures a safe and very sturdy soldered connection that will not introduce any voltage drop or errors in the voltage signal being provided. The positive aspect of our design is that it is manageable when creating the final layout of the eGOAT: the position and location of every component. Certain wires or connections should not be long enough to introduce more resistance. The motors and the power source both enter the same terminal on our motor controllers , we do not want the wire length of the power source to be long enough to introduce a voltage drop and we do not want the same with the actual connection of the motors to the terminal either. This is why having a controller external of the pcb is critical.

Our design does not incorporate a charging mechanism. Through research on solar panels and charging,we decided not to incorporate solar charging because of the lack of effectiveness of its performance , budget and real estate on our system onboard. Solar panels for this system would have to be a small size which means little charging capabilities. Through review of dimensions and space on the eGOAT there would be little room for it to operate. The effectiveness of charging all stems from the size , efficiency and total output of the solar panel, they all tie in together and led to the decision not to use any charging mechanism.

Figure 6.8 Hardware Layout



6.2. Software Design

The command and control paradigm of the eGOAT can be best modeled as a hybrid deliberative-reactive architecture utilizing three control layers. They are, from top to bottom, the administrative/communication layer, the planning/control layer, and the reactive/manipulation layer. In general each layer is subservient to the commands of the layers above it. Circumstances in which this hierarchy is violated are discussed in the section on the reactive/manipulation layer below.

6.2.1. Administrative/Communication Layer

The administrative/communication layer is responsible for managing and distributing all external communications to and from the eGOAT. Within this layer, the hardware controller is responsible for establishing and maintaining a

Wi-Fi-based local area network (LAN) and managing LoRa communications. These wireless connections are used to process external commands, adjust operational policies, and provide diagnostics information.

6.2.1.1. Diagnostics System

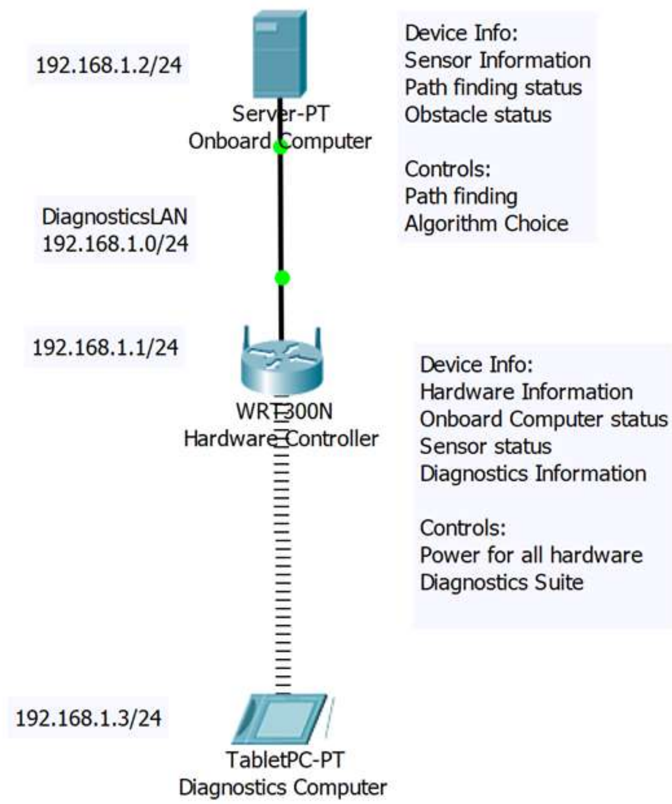
The diagnostics system provides a suite of administrative and diagnostic tools. This gives users the ability to access and change a variety of system information and operational parameters.

6.2.1.1.1. Wi-Fi Diagnostics Network

The Wi-Fi LAN will be using 802.11n protocol to integrate the hardware controller and onboard computer network interfaces into a unified diagnostics network. Although this network connection provides a convenient, high-bandwidth, and flexible means of communication between the hardware controller and onboard computer, it is unnecessary, potentially unreliable, and far too power-intensive for normal navigation and control operations. It is only turned on when the diagnostics network is in use.

However, the hardware controller will be the host for all connections because it is the only Wi-Fi controller that will always be on (except during times of extremely low power). The onboard computer will be a member of the hardware controller's network, so that both will be accessible from the same connection. For example the hardware controller will be the network host with the IP 192.168.1.1 while the onboard computer will be a network member with an IP of 192.168.1.2. Using this topology, a web page loaded from the hardware controller's network will contain all required information from the hardware side of the robot, while also being able to pull additional information from the onboard controller if it is online. That way the robot's state will always be accessible regardless of what hardware is online or the state of the onboard computer. This will also help with hard rebooting specific components if needed. A general purpose computer can then be connected to the eGOAT's local network and a client GUI displayed. This GUI will then allow the user to read and alter various data on the eGOAT. **Figure X.X** below shows a diagram of how the client-server stack for the diagnostic system will be constructed.

Figure 6.9: Diagnostic and Control Client-Server Stack



6.2.1.1.2. Diagnostics Server

The diagnostic server is responsible for providing status information of all available hardware, readouts of the event queue, and a list of self-tests for each component. This information will be provided on a web page accessible on the local eGOAT Wi-Fi network called the diagnostics panel. The diagnostics panel will include two sections, depending on which system the information comes from, with the list of each being amended to as needed in the second half of the project.

The hardware controller will contain all hardware related information, as well as low level diagnostic tools and power controls for all components.

Hardware Information

- Battery status
- Cameras status
- Lidar status
- Cutting heads state and current commands

- Wheel motors state and current commands

Hardware Control

- Turn on/off power to all available components
- Power cycle onboard computer
- Send commands to onboard computer
- Add/Edit/Delete commands for all motors

Communication Information

- Hub connection and command logs
- BLE radio output

The onboard computer will contain all software related information, and the ability to change a range of algorithmic values. It will also contain both the raw sensor data and post-processed data from each.

Software Data

- Raw sensor data
- Post-Processed sensor data
- Path finding algorithm output
- Past path history (where memory permits)
- List of detected objects and detected object types
- Grass lengths in both directions
- Add/Edit/Delete commands for onboard computer

Control Panel

- Pathfinding editor
- Algorithm value editor

6.2.1.2. LoRaWAN Connectivity

Wi-Fi will be used for local connectivity, but a longer range, low-latency protocol is still needed for large field deployments as well as real-time implementation of safety protocols. This fast, long range connection will be realized using LoRaWAN in a hub and spoke topology network. Currently the implementation of the hub is trivial, it is merely a laptop with a known interface through a LoRa transceiver, however this could easily be scaled up to a much more extensive and coordinated operation in the future.

Although LoRaWAN connection itself is managed as part of the administrative/communication layer, its primary purpose as a real-time safety measure is actually implemented in the reactive/manipulation layer, bypassing the usual control hierarchy. This behavior will be discussed in more detail in that section below, but in summary the the LoRaWAN allows the interruption and temporary halting of all motor operations via kill command from up to 1 km away.

6.2.2. Planning/Control Layer

The planning/control layer is responsible for all high level task planning and data processing, and is primarily implemented within the onboard computer. These responsibilities include processing all input from the LIDAR and computer vision camera, synthesis of all sensor data, mapping and navigation algorithms, and overall goal management. The software required to perform, manage, and integrate these tasks effective is extremely difficult to develop and demanding on the hardware; to realize the eGOAT system, we will be making use of the Robot Operating System (ROS).

ROS is a framework for writing robot software. It is intended to simplify robot behavior with the many robotic platforms available. It is intended to streamline and combine knowledge on robotic software to help everyone using it to benefit from each other, also preventing redundant software creation. ROS's main client libraries are designed with C++ and Python languages and are intended to be used with Unix-based systems. ROS is intended to use the packages available to it in order for users to have an open source implementation of common robotic algorithms and functionalities. While ROS is not actually an operating system in the traditional sense, it does provide the capabilities that you would expect an operating system to do, such as hardware abstraction, message passing between processes, package management, and low-level device control.

ROS accomplishes the task of providing robots with these fundamental controls solutions by distributing the framework for processes that were previously developed by another software developer, these frameworks are called nodes. These nodes, when sorted out and combined serve as a package for use in more general developments. ROS is intended to be thin meaning it will work with many different software frameworks. ROS includes built in frameworks for testing where this feature is not common in similar robotic frameworks. ROS also allows for scaling into much larger development process providing a valuable resource for projects that start to increase into much more involved processes as they are being developed or improved.

6.2.2.1. Sensors

Each sensor is modeled internally with a statistical model of its accuracy. This model represents the statistical likelihood that a sensor will detect an obstacle in a given position given that position actually *is* occupied by an obstacle. The equation representing this probability is given in **Equation 6.1** below. These statistical models of each sensor will be found experimentally as development continues

The readings of each sensor on this position are then synthesized into a statistical point map and dynamically updated as more data becomes available. Baye's theorem is used to combine these probabilities and is given below in **Equation 6.2**.

Equation 6.1: Sensor Model of Hypothetical Sensor S

$$Probability\ of\ sensor\ detection\ (S)\ given\ occupied\ cell\ (o)\ =\ P(S|o)$$

Equation 6.2: Baye's Theorem

$$P(o|S) = \frac{P(S|o)P(o)}{P(S)} = \frac{P(S|o)P(o)}{P(S|o)P(o)\ +\ P(S|\neg o)P(\neg o)}$$

6.2.2.1.1. LIDAR

The LIDAR is the primary rangefinding sensor that the eGOAT will use to construct its occupancy map. It allows for highly accurate rangefinding capabilities in all directions around eGOAT with a resolution measured in centimeters. However, the LIDAR is only capable of collecting range data in a 2D plane around the eGOAT, meaning that it will need help from other sensors to detect difficult terrain or obstacles that sit on the ground below the LIDAR's vertical range.

6.2.2.1.2. Computer Vision

The eGOAT is equipped with forward-facing and backward-facing 720p webcams that it will use to capture video footage during normal grass cutting operations. This video footage will then be processed by computer vision (CV) software in order to aid the eGOAT in task planning and navigation by recognizing uncut grassy areas, helping to verify LIDAR readings, and identifying obstacles that may lie below the LIDAR's view. Because CV algorithms are so computationally expensive and often require specialized hardware in order to be run in real-time, the majority of CV operations will occurs in the USB-attached graphics coprocessor.

Open Source Computer Vision (OpenCV) is a library of programming functions designed for real-time computer vision. Through the OpenCV-Python and Numpy (a highly optimized library for numerical methods) we can create fast prototyping of computer vision problems with Python. The device will have the attached camera feed the visuals of the grass plain and obstacles which, using OpenCV-Python, can be converted into the necessary format for the motion planning algorithms.

6.2.2.1.3. Hall Effect Encoder Odometry

The actual implementation of the Hall Effect encoders actually exists within the reactive/manipulation layer, the planning/control layer has no direct knowledge of it. Instead, the planning/control layer has statistical and kinematic models of the encoders' accuracy, the motor control algorithms used by hardware controller, as well as the physical properties of the eGOAT itself. When the hardware controller notifies the onboard computer that a given move operation is complete, the eGOAT can use this information to maintain an accurate model of the system's odometry, which will prove critical in maintaining localization within the environment.

6.2.2.2. Simultaneous Localization and Mapping (SLAM)

SLAM is designed to create and update a map within an unknown environment while keeping track of the robots location. SLAM is not a specific algorithm, but more of a set of algorithms and technologies that work on solving localization (where the device is) and mapping the landscape at the same time. Another important point of SLAM is that it must work in real-time. SLAM finds the position by combining the measurements of points made over a set of frames. SLAM's way of optimization is finding the best position for the camera to be able to always deduce its location. The consensus is that the best method is the bundle adjustment. The bundle adjustment gives the best starting configuration and gives the minimum error. A key problem with it is that it is very time consuming, a solution to this is the advent of multicore computing. It allows one core to focus on mapping in real time and the bundle adjustment can take its time in another core.

Another key feature of SLAM is loop closure, a large scale mapping technique that is most certainly needed for something like the E-GOAT. The key points of this feature is to reduce error by associating a previous tracked location with a current one. Over more and more iterations the map will become much more accurate. Another valuable technique is relocalisation which allows the device to reset it position to a previously safer view that is similar to the one it is currently seeing when the now registered position results in a system failure.

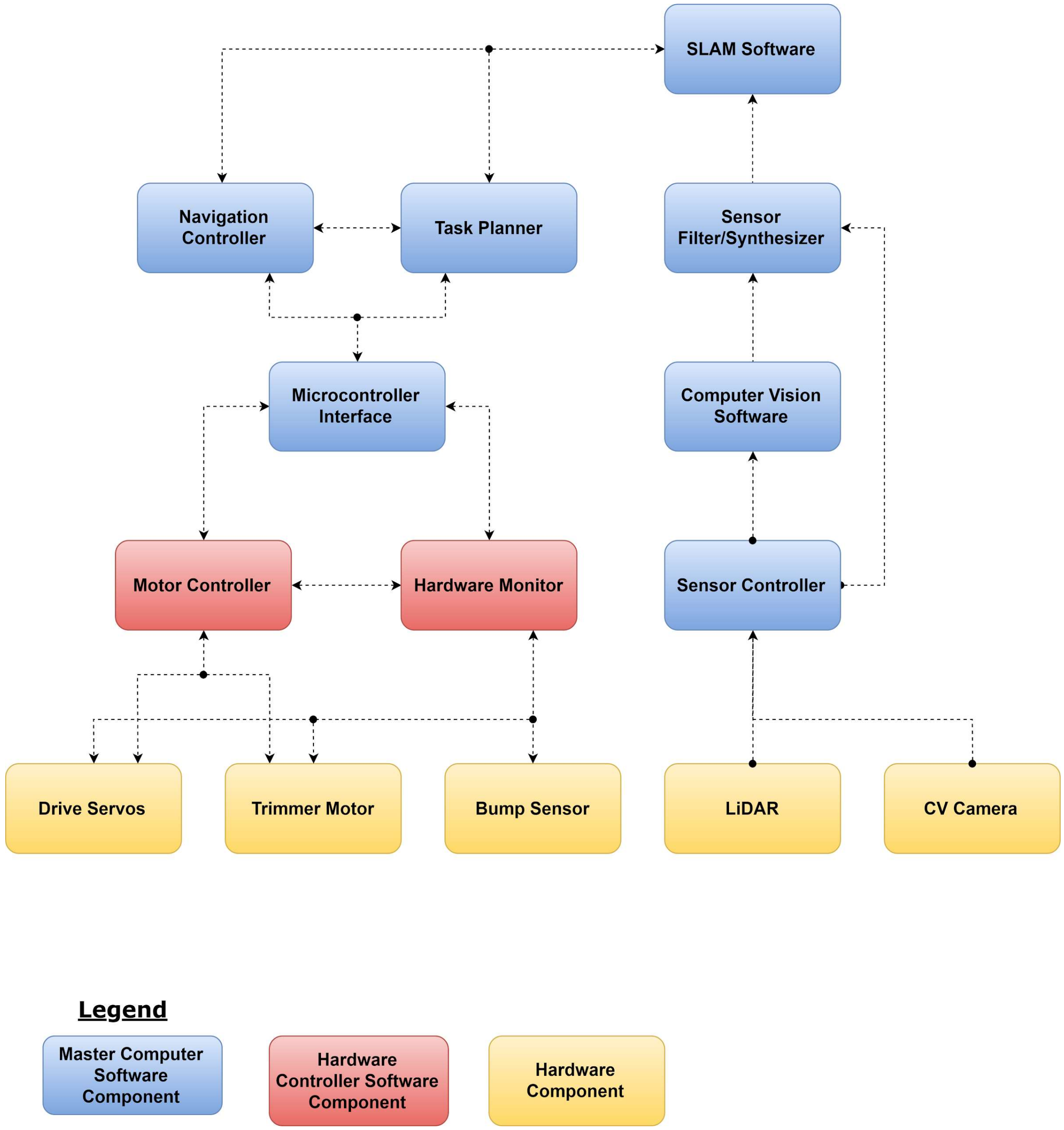
6.2.2.3. Task Planning and Navigation

As the eGOAT explores and constructs a map of its environment, it also builds and maintains a prioritized list of tasks to complete. The system then uses this data in a path planning algorithm to find the optimal path to complete its objects. In robotics the optimal path is most the one with the physically shortest distance. The eGOAT's main objective is to cut all the grass available and that would include all physical space not occupied by a obstacle. This essentially means we have to design our algorithm cover all the registered map data while avoiding obstacles. It is more reminiscent of a pacman scenario where the walls are our boundaries, the ghost are our obstacle, and we must touch on all the pellets in order to consider it a completed job.

Dijkstra's, A*, and other common path planning algorithms may still be valuable in certain cases, but as it stands they are only looking to find the shortest distance, and in our case the optimal path isn't the shortest distance from point A to point B. We require a that all locations are visited and these algorithms don't keep that in mind. Pathfinding algorithms based on completing prioritized objects, such as D*, D* lite or D* field may prove more valuable.

Once the pathfinding algorithm has constructed a path to its next objective, this path is broken up into a series of waypoints and commands that can be performed by the hardware. These commands can generally be separated into two groups: time-based commands, which can be queued and performed asynchronously such as changing the eGOAT's speed or toggling the trimmers, and sequential commands, which must be performed one after another such as move commands. As commands in theses queues are added or edited, the changes are transmitted over UART to the hardware controller and added to its own copy of the queues. Upon receiving confirmation from the hardware controller that a task has been completed, the task is removed from the onboard computers queues as well. **Figure 6.9** below

. Figure 6.9 Navigation & Sensor Stack Block Diagram



6.2.3. Reactive/Manipulation Layer

During normal operation, the reactive/manipulation is primarily concerned with receiving, interpreting, and performing commands sent by the planning/control layer. However, the reactive/manipulation layer is also capable of bypassing the normal command hierarchy and overriding those commands in order to respond to emergent stimuli in immediately. These tasks could be have conceivably been performed by the onboard computer directly, however it was decided that direct motor control and emergency signals should be handled by a dedicated hardware controller in order to ensure they can be managed in real time.

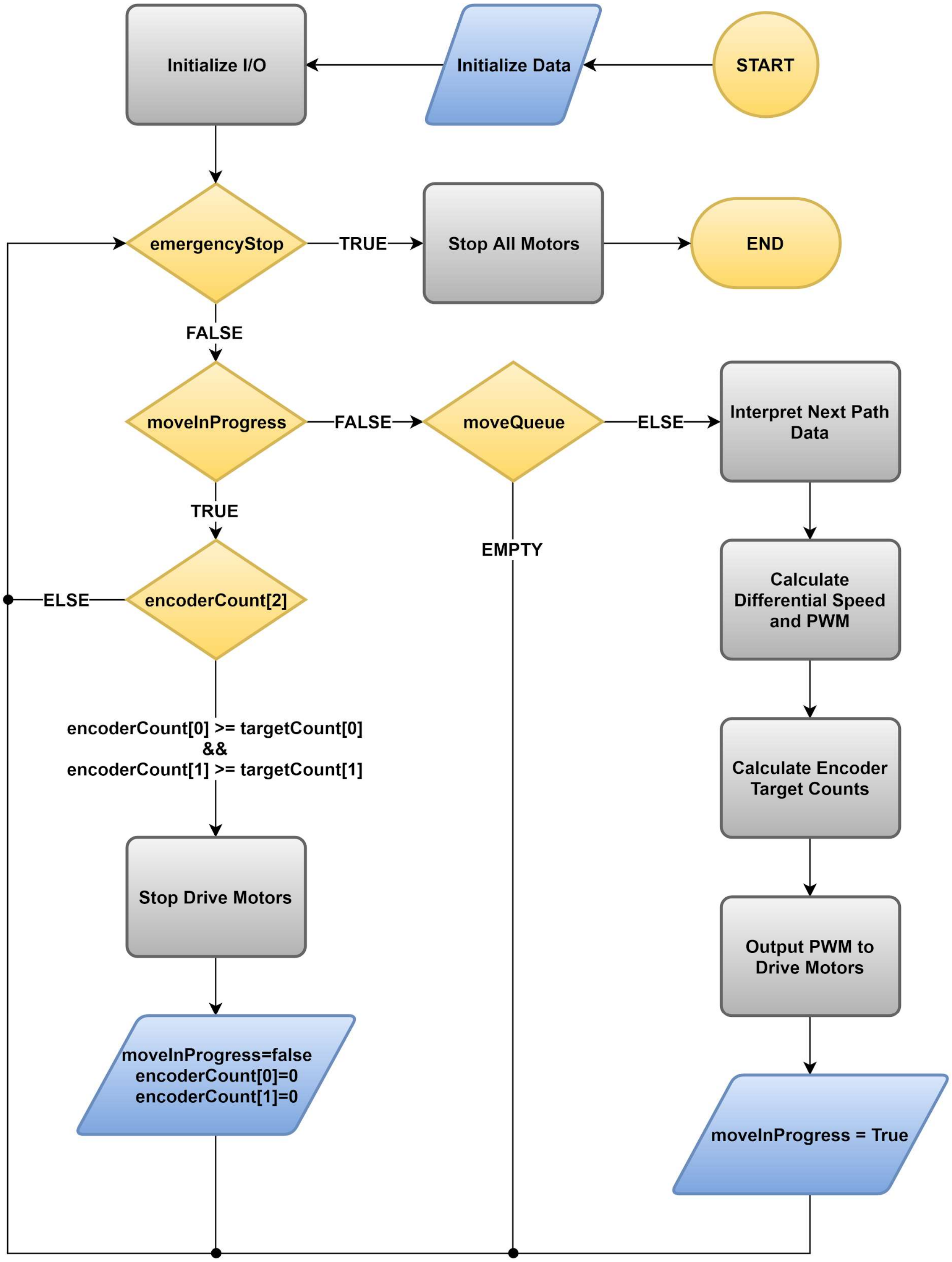
As already discussed, the planning/control layer breaks up its long-term goals into time-based, asynchronous tasks as well as sequential tasks that are then passed to the reactive/manipulation layer of the hardware controller via UART connection. The hardware controller maintains both types of commands in separate time-based and sequential command queues. These commands can be stopped and changed by the planning/control layer at any time as well notified when they are complete.

6.2.3.1. Motor Manipulation

The majority of commands sent by the planning/control layer will be concerned with the manipulation of the eGOAT's motors to perform movement and trimming tasks, although the planning/control layer is also able to request a variety of sensor and internal state information. The hardware controller manipulates the motors by outputting a directionality flag and pulse width modulation (PWM) signal to the speed controllers, which then use the primary motor power supply to amplify the PWM signal.

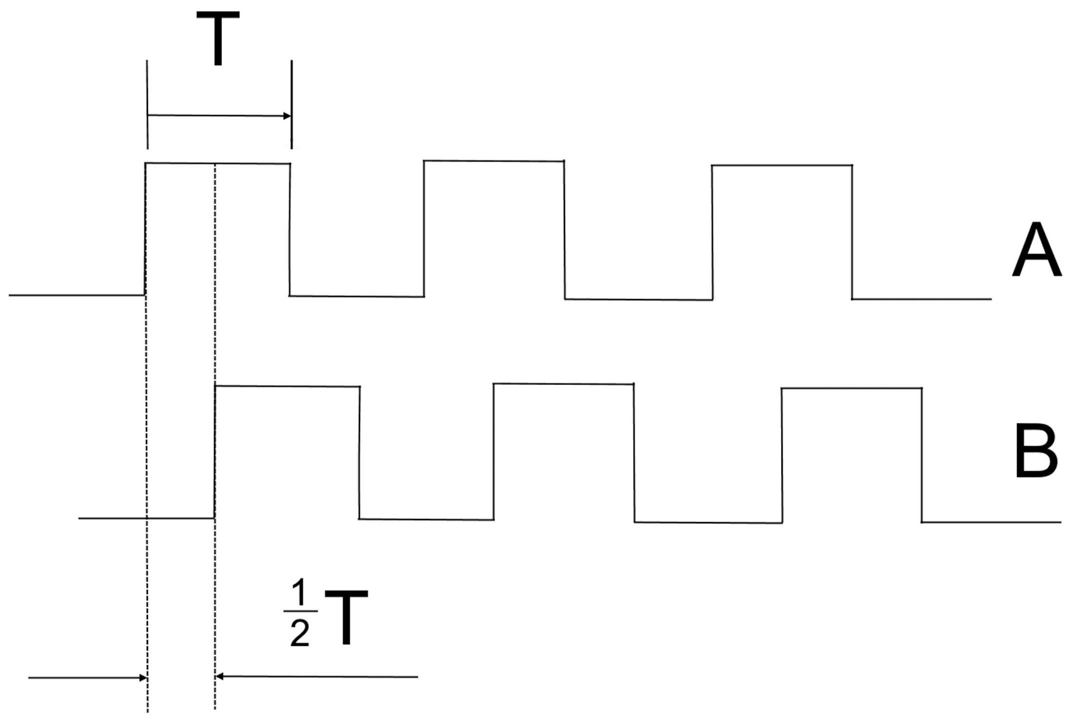
The hardware controller contains integrated peripherals capable of generating a PWM modulation signal and can be easily defined in software by its frequency, duty cycle, and resolution in order to alter the speed of the motors. Each move command comes as a series of waypoints and simple definition of the type of path the eGOAT will take, it is then up to the hardware controller to use its kinematic model of the chassis and motors to calculate the differential drive's speed ratios and expected odometry. The motor control loop is shown below in **Figure 6.10**.

Figure 6.10 Motor Control Loop



Odometry measurements are obtained from Hall effect encoders attached to the drive motors. Each of these sensors outputs two square waves signals **A** and **B** which are out of phase by 90 degrees. Each cycle of this signal represents a certain amount of turning performed by the motor, which can then be used in conjunction with the wheel radius and gearing to calculate the distance traveled. Each cycle of **A** is calculated at its leading edge and compared with that motors kinematic target value. Signal **B** is just used to determine the direction of the motor's spin. **Figure X.X** below shows the output signal of the Hall effect encoders.

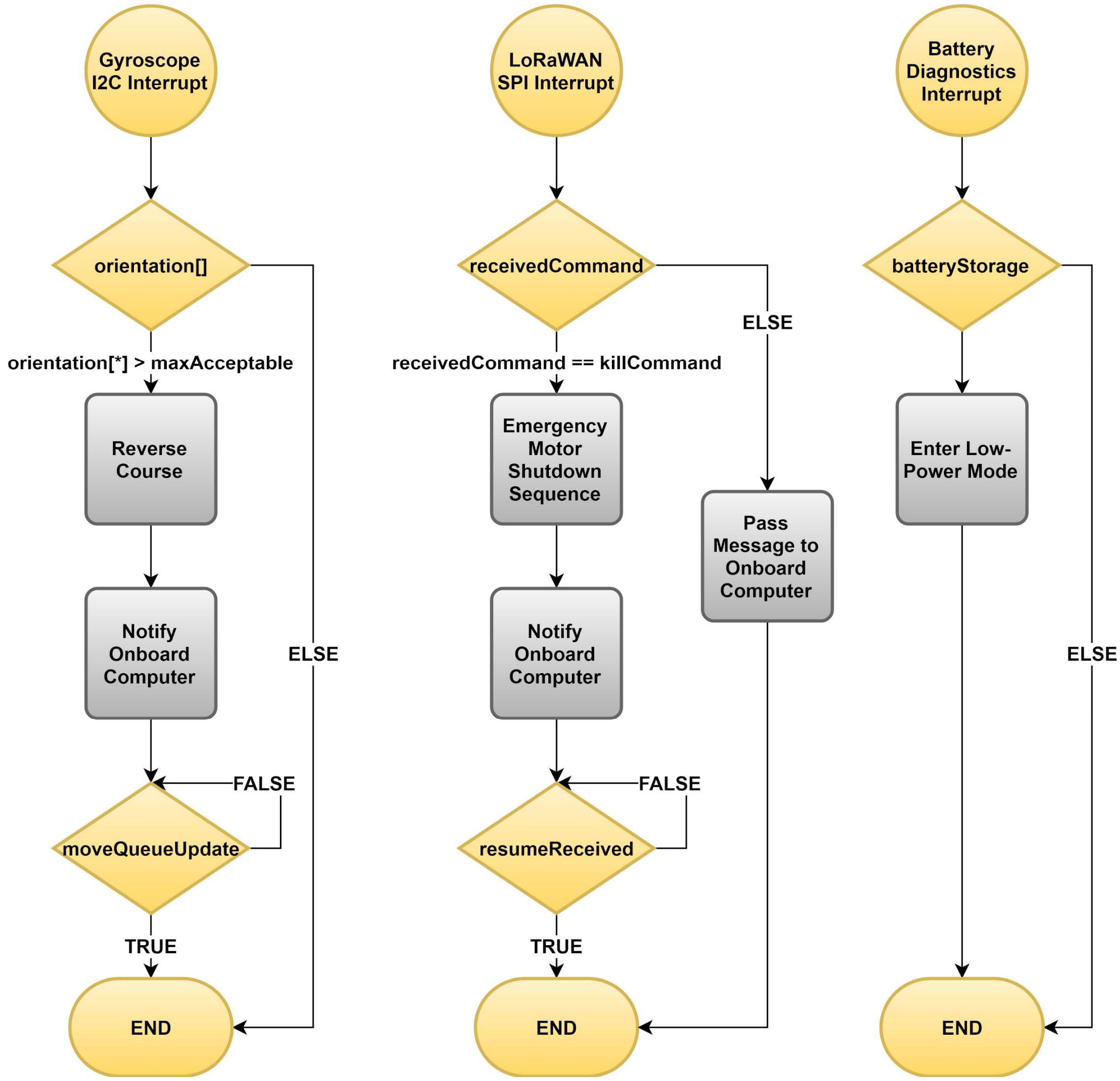
Figure 6.11 Hall Effect Encoder Square Wave Output



6.2.3.2. Hardware Controller Interrupt Protocols

The hardware controller is primarily concerned with running the software needed to respond to situations that must be dealt with in real time, especially those concerning the safety of the eGOAT and the humans around it. Because of this, it must also be able to control the movement and trimming of the robot in a fast reactionary manner, and as such also behaves as the motor controller and is responsible for receiving and interpreting commands from the main computer. These safety protocols use interrupt driven software to override ongoing processes. **Figure 6.12** below summarizes these interrupts.

Figure 6.12: Hardware Controller Interrupt Diagram



6.2.3.2.1. Kill/Power-Down Command

The Hardware Controller will have a direct line to the physical kill button, which will act as a direct hardware interrupt, and immediately initiate a full hardware shutdown. All outside physical motors will be immediately shutdown, while attempting to perform a graceful shutdown of the onboard computer to avoid any potential corruption problems. The central hub will be notified that a physical kill command was issued along with the current GPS coordinates of the robot. Once the onboard computer has shut down or a specified period of time has elapsed, whatever happens first, the Hardware Controller will cut power to the onboard computer and all sensors. It will remain in a low power state until a powerup command is issued.

1. Immediately kill power to all motors
2. Attempt graceful shutdown of onboard computer

3. Notify central hub that a kill command was issued via the physical button
4. Cut power to onboard computer
5. Cut power to sensors
6. Enter low power state until central hub or a local user issues powerup command

The hardware controller will also be responsible for responding to nearby proximity beacons. Upon receiving a BLE beacon that a user is nearby, the Hardware Controller will shut down all motors and notify the onboard computer to temporarily halt sensor processing. The Hardware Controller will notify the central hub that a user is in the area, along with the BLE beacon ID, and that it is currently in a standby mode. It will remain in standby mode until no more BLE beacons are received within a specified time period. When that happens it will notify the onboard computer to resume sensor processing and return power to the motors once the onboard computer gives its first instructions.

1. Kill power to all motors
2. Notify onboard computer of user and to pause sensor processing
3. Notify central hub that a user is nearby and robot is in standby
4. Wait until user has left the area
5. Notify onboard computer to resume processing
6. Return power to motors and resume cutting

Finally, the hardware controller will also handle any remote commands received through the LoRa module. Upon receiving a remote kill command the Hardware Controller will shut down all motors and notify the onboard computer to temporarily halt sensor processing. The Hardware Controller will notify the central hub that the kill command was received and the robot has successfully entered standby mode. It will remain in standby mode until a powerup command is issued by either the central hub or a local user. If a local user issues the command the Hardware Controller will notify the central hub that a local user issued an override powerup command and that the robot is returning to fully active status.

1. Kill power to all motors
2. Notify onboard computer of kill command and to pause sensor processing
3. Notify central hub that robot has successfully entered standby
4. Wait until a powerup command is issued
5. Notify onboard computer to resume processing
6. Return to fully active status, resuming whatever work the robot was doing previously

6.2.3.2.2. Low Battery Power-Down Sequence

If for any reason it the eGOAT reaches a low power status (~10% charge) and cannot be recharged in time it will follow the following procedure:

1. Notify central hub of low power status, with GPS coordinates of last known position.
2. Turn off all peripheral sensors, chips, hardware except the hardware controller. At a set interval it will turn the LoRa antenna on to report its current battery percentage and status to the central hub, before returning to low power mode. The Wifi diagnostics network will also be shut off unless the controller hub specifically requests it to be turned on for diagnostics by a technician.
3. This will continue until the battery level reaches the critical inoperable point for the installed Lithium batteries. During this time the central hub will be notifying the owners of a cutter in need of assistance / maintenance.

6.2.3.2.3. Gyroscope Warning

If any of the eGOAT's orientation readings exceed acceptable limits, then the reactive/manipulation layer will follow the following procedure:

1. Reverse course along the same path until readings fall significantly below safety margins.
2. Notify the planning/control layer, which will mark the position as hazardous on the map.
3. Await course correction from planning/control layer.

6.3. Mechanical Design

The mechanical design will comprise of propulsion , structure of the eGOAT, and the implementation of trimming , and traction of the eGOAT. The mechanical design was done by the mechanical team who had given input on the components such as the drive motors, and the trimmer motors that needed to be electrically powered. The mechanical design is incomplete and does not give to many details to all the facets of the design due to the academic timeline of the mechanical team.

6.3.1. Motors and Driving method

The drive motors were selected to fit the design requirement to move the eGOAT. The motors need to be low speed and high torque due to the weight of the eGOAT will hold. In this project the differential steering method will be applied to the robot. This method is one where the motor speed for each wheel is altered in order to change the directions and take turns. For example, if the robot needs to make a complete 360 degree spin each of the two adjacent wheels will rotate at the same speeds in opposite directions. This allows it to make sharper turns in less space than other steering systems. When designing the chassis one should also take note that by decreasing the distance between the front and rear set of wheels results in a better zero-turn radius.The wheels selected were - Traction Lug 10 x 3.50-4 Tiller Tire these help with the traction on the ground the eGOAT will have to operate on.

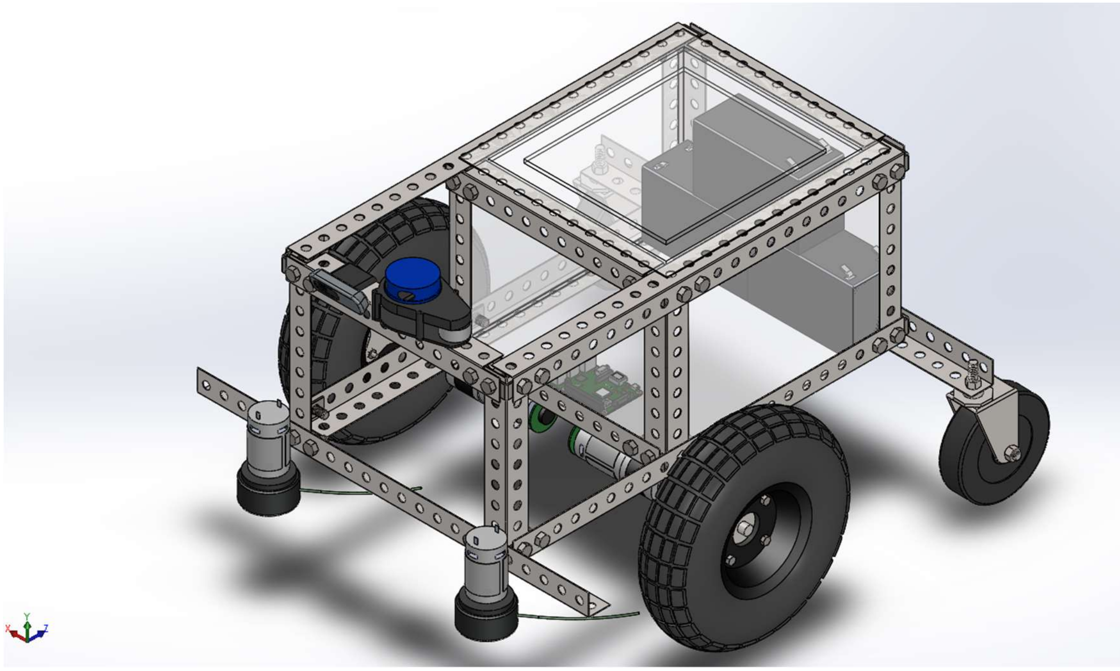
6.3.2. Trimmers

The trimmer motors will be Ryobi 18-Volt Lithium-Ion Cordless String Trimmer, which was selected for its off the shelf categorization and low weight. The trimmers will be attached to a trimmer string. The trimmer string selected will be a star shaped string which allows for more cutting surface over a blade of grass. The diameter of the trimmer string is extremely important because the thicker the line, the stronger and more durable it becomes. This allows it to easily and efficiently cut through grass. The diameter of trimmer string ranges from 0.065 - 0.085 inches for light to medium work, 0.085 - 0.110 inches for medium to heavy work, and anything larger than 0.110 inches is for mostly very heavy work, such as grass and large or small weeds. It is important to note that the diameter of the trim string also correlates to the rotational speed. This speed, which can range from 2000 RPM to 20,000 RPM, is in relation to the weed trim line diameter.The larger the diameter the less RPMs can be achieved.

6.3.3. Structure

The structural integrity of the eGOAT is needs to be able to withstand the environmental factors that could affect its functionality. As seen in figure 6.13 the primary construction consists of “L bars” also known as punched angles, of varying lengths, with holes punched every inch on both faces. The L bars are connected together by right-angled “L brackets” with 4 holes for 4 bolts. The result is a rigid rectangular frame to which the other components are mounted. There is a partition slightly forwards from center that separates the front structure from a rear enclosure that houses the batteries and electronics. The drive motors are attached to the L bar on the bottom of the partition. The drive wheels with pneumatic tires are in turn attached to the motor shaft with a hub. Two caster wheels in the back allow differential steering by the front wheels, and are height adjustable using spacers on the threaded mounting stud. Two trimmers are fixed to L bars on the front of the mower such that they are height adjustable as well.

Figure 6.13 Mower Isometric View



7. System Demonstration and Testing

To help ensure that the components we designed for the eGOAT work we had to test them. For circuits we tested them using 2 checklists. A software driven test where we simulated the circuits using circuit simulation software. Then we breadboard tested our circuits to make sure we knew how to connect everything correctly and that it worked in a real environment. Testing was done in the electronics lab in the engineering building and used power supplies, voltage and current meters, and common electronic components. The testing helped us understand first if our design was going to be acceptable for our printed circuit board, and would be able to be replicated in the real world.

7.1. Step Down module

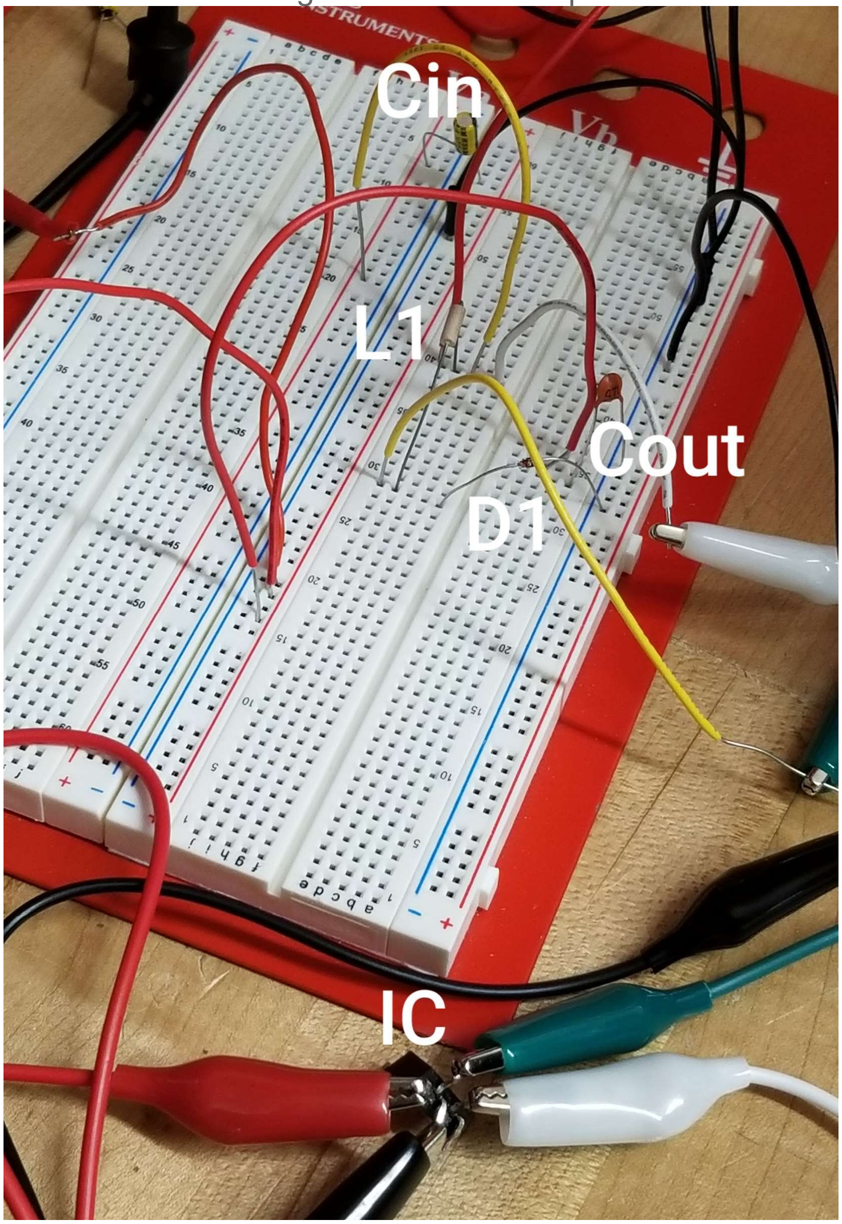
Our 2 step down voltage module or buck converter was tested using a breadboard. The breadboard testing helped to understand that all the components needed would help get the desired output. There were two step down modules that needed to be created. A 12 to 5 V and a 12 to 3.3 V step down. When creating both circuits on the the breadboard we used a single grounding point for all connections that needed to be grounded. This allows for ease of testing and ease in design when connecting. Testing for the step down modules were simplified due to the integrated circuit we are using.

Four the 12 to 5V step down testing we used 4 out of the 5 pins. The on/off pin does not need need to be connected to have the ON function enabled. Applying the 12V source we saw a 5V connection which was our desired output.

The 12 to 5V step down breadboard testing was created using the following components as seen in **figure 7.1** below:

- **IC:** Regulator:LM2596
- **Cin**: 39uF capacitor
- **Cout:** 4.7uF capacitor
- **L1**: 33uH Inductor
- **D1**: Schottky diode

Figure 7.1: 5 volt step down

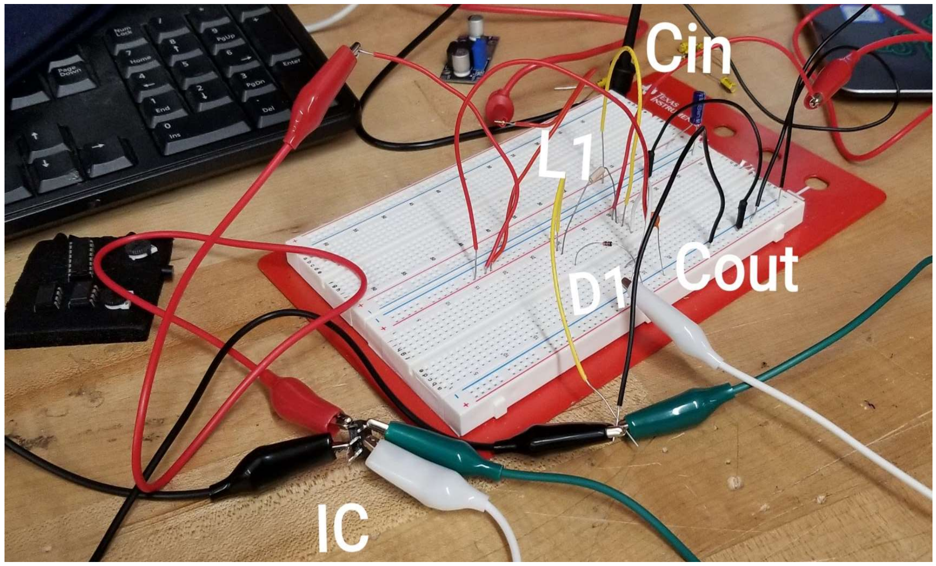


For the 12 to 3.3 volt step down module we also did not use the 5th pin on the LM2596. The on/off pin should never be energized in our design because it turns off the IC thus shutting down our power distribution.

The components as seen in the **figure 7.2**:

- **IC1:** Regulator LM2596
- **Cin**: 100uF capacitor
- **Cout**: 4.7uF capacitor
- **L1**: 33uH Inductor
- **D1**: Schottky diode

Figure 7.2: 3.3 volt step down



The tested circuits are the same layout and connections of the eagle schematics shown in the Hardware design section. They all gave the required output and were in the right orientation. These have been approved for the use in our pcb to step-down the voltages for the components needed.

8. Administrative

8.1. Estimated Budget and Financing

Table 8.1 below shows the estimated budget distribution for the eGOAT project. A large portion of the budget is dedicated to generic mechanical hardware.

Table 8.1: Budget and Financing

Item	Budgeted Cost
Single Board Computer	$100.00
Microcontrollers	$50.00
Printed Circuit Board	$50.00
Battery/Charger	$150.00
Sensors	$200.00
Motors/Servos	$150.00
Cordless Electric Trimmer Components	$200.00
Mechanical Hardware	$600.00
Total	$1,500.00

8.2. Milestones

Table 8.2: Milestones and anticipated schedule

Senior Design 1 (2018)	
Description	**Due Dates**
Project selection	August 31st
Divide and conquer	September 14th
Research	October 10th
60 Page	November 2nd
100 Page	November 16th
Finalizing the paper	November 24th
Final document	December 3rd
Senior Design 2 (2019)	
Description	**Due Dates**
Order PCB #1	January 8th
Finalize PCB#1 Testing	January 18th
Order PCB #2 and Testing	January 25th
Build prototype	February 1st
Testing	February 4th - February 18th
Finalize prototype	March 22nd
Peer presentation	TBA
Final report	TBA
Final presentation	TBA

8.3. Senior Design 1 Project Timeline

This is a timeline of significant events that have occured during the first semester. Many of these have delayed or impacted the project's development.

Table 8.3: Senior Design 1 Project Timeline

Date	Description
August 31st	Project selection, initial requirements received
September 14th	Divide and conquer
September 27th	First meeting with client to clarify requirements
	Client removes solar panel requirements, invalidating previous solar research
	Client states battery will likely be provided, promises to return with clarification shortly, placing a hold on battery research
October 18th	Receive clarification from client that batteries will not be provided; battery research resumes
November 2nd	60 Page
November 8th	Receive component decisions and specifications from ME and CS team
November 9th	Received instructions on ordering through the MAE department to access budget
	Begin ordering parts
November 13th	Sent out email to professors Eduardo Lopez, Lei Wei, and Richie explaining issues ordering parts
November 14th	Informed by MAE ordering department that component orders were on hold until an account number became available
November 15th	Second meeting with client
	Client informs us pre-cutting grass is much taller and terrain much rougher than previously specified
	Client requests higher torque trimmer motor, requiring new component research and a redesigned power circuit
November 16th	100 Page
	Received account number for purchases from MAE department, orders begin to process
November 27th	First component order begin to arrive, still awaiting most others as of December 2nd
November 28th	Initial Breadboard Testing Begins
December 3rd	Final document

9. Appendices

9.1. Appendix A: Copyright Permissions

Figure 5.1

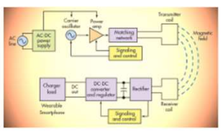
To Karen.Field@informa.com

Cc

Permission to use picture for Senior design project

Hello,
I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use the wireless battery charging figure in our paper from the following link. Thanks.

https://www.electronicdesign.com/power/wireless-battery-charging-not-just-smartphones



Wireless Battery Charging Not Just for Smartphones | Electronic Design

www.electronicdesign.com

A streamlining of the standards and ever-smaller ICs could make wireless charging viable in wearables and other portable devices.

Hello,
I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use the wireless battery charging figure in our paper from the following link. Thanks.

https://www.electronicdesign.com/power/wireless-battery-charging-not-just-smartphones

Figure 2.4

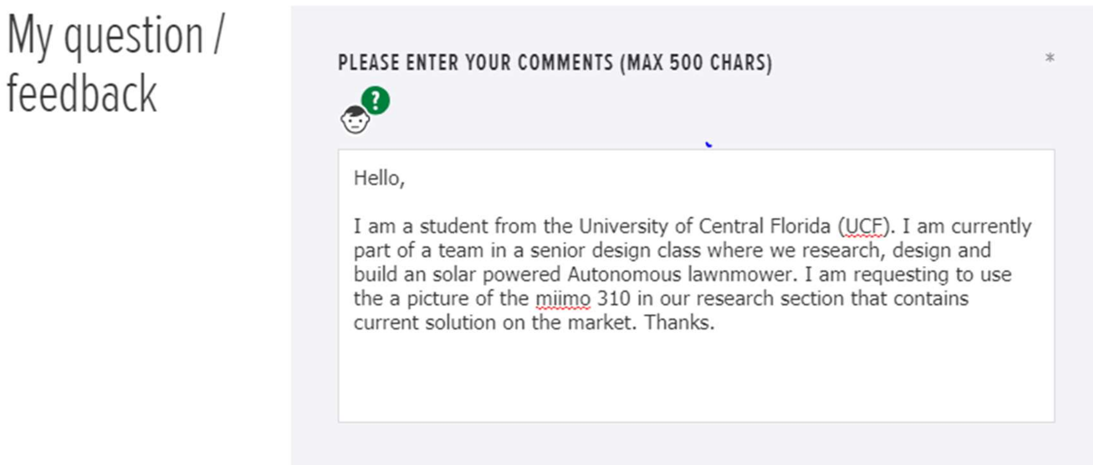
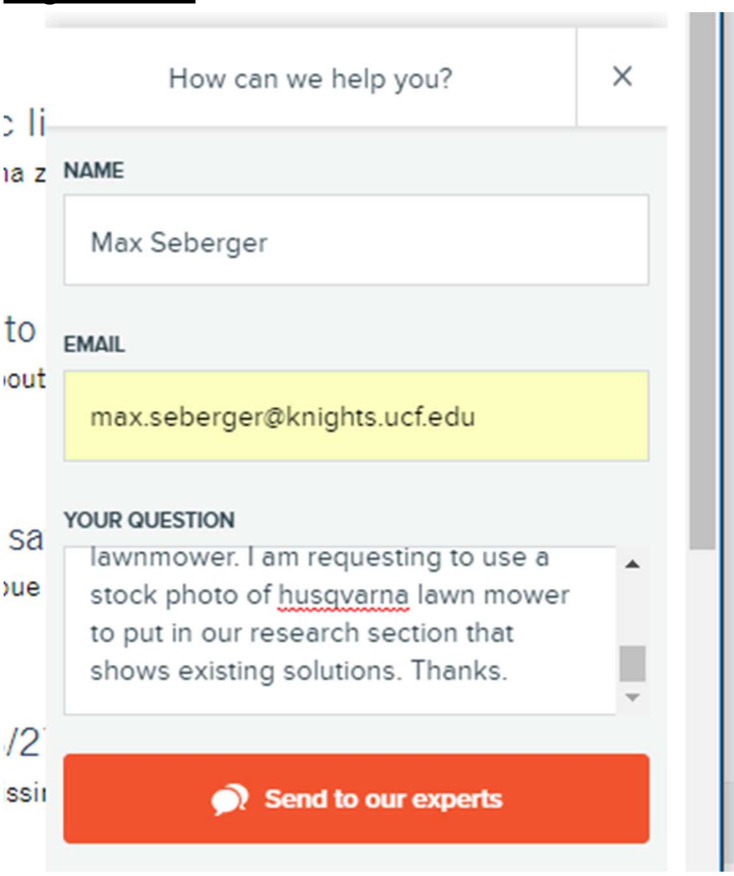


Figure 2.3



I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a stock photo of husqvarna lawn mower to put in our research section that shows existing solutions. Thanks.

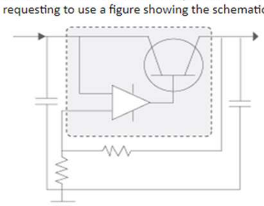
Figure 5.2

To R renesasrulz@renesas.com × Bcc

Cc

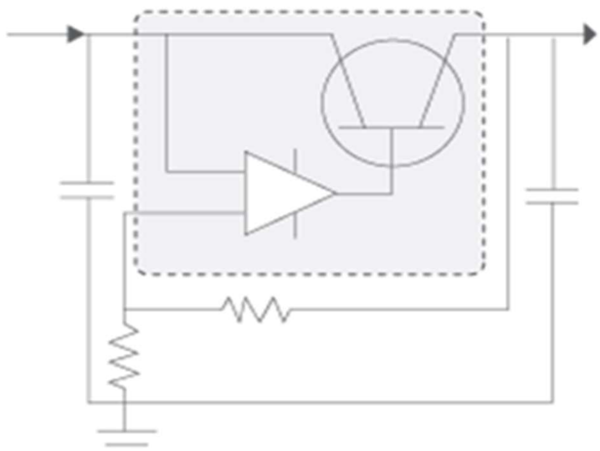
Add a subject

I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a figure showing the schematic of a linear regulator. Thanks.



https://www.renesas.com/us/en/products/power-management/linear-vs-switching-regulators.html

I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a figure showing the schematic of a linear regulator. Thanks.



https://www.renesas.com/us/en/products/power-management/linear-vs-switching-regulators.html

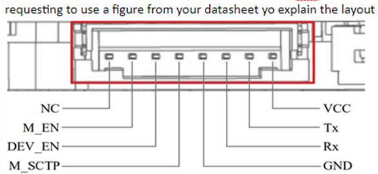
Figure 6.6

To eai@eaibot.com Bcc

Cc

Permission to use picture for Senior design project

Hello,
I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a figure from your datasheet yo explain the layout of the lidar. We will be using a YDLIDAR X4 in our senior project. Thanks.



https://www.superdroidrobots.com/product_info/TS-082-0X4.pdf

YDLIDAR X4 Datasheet - superdroidrobots.com
www.superdroidrobots.com
www.eaibot.comCopyright2015-2017EAITeam 1/9 CONTENTS Introduction.....2

Hello,
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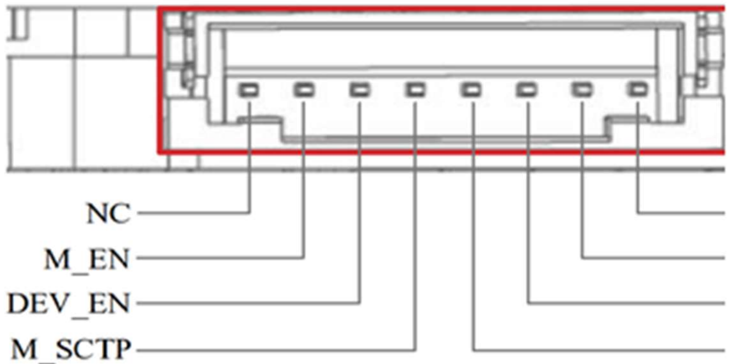


https://www.superdroidrobots.com/product_info/TS-082-0X4.pdf

YDLIDAR X4 Datasheet - superdroidrobots.com

×

www.superdroidrobots.com

Figure 5.3

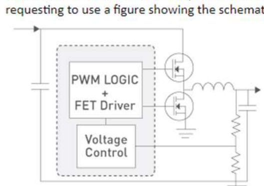
To renesasrulz@renesas.com ×

Bcc

Cc

Permission to use picture for Senior design project

I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a figure showing the schematic of a switching regulator. Thanks.



https://www.renesas.com/us/en/products/po (Ctrl) ment/linear-vs-switching-regulators.html

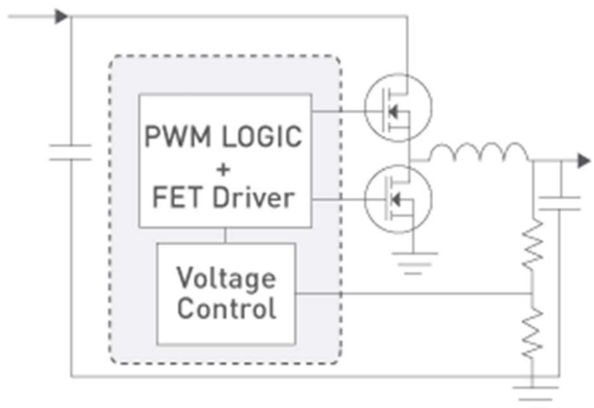
Linear vs. Switching Regulators | Renesas Electronics

×

www.renesas.com

Learn how to decide if a low powered linear regulator or highly efficient switching regulator is a better option for your design.

I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a figure showing the schematic of a switching regulator. Thanks.



(Ctrl)

https://www.renesas.com/us/en/products/p[...]
management/linear-vs-switching-regulators.html

Figure 5.11

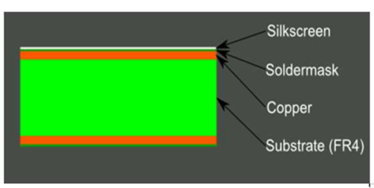
To support@sparkfun.com

Bcc

Cc

Permission to use picture for Senior design project

Hello,
I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use the figure showing the the layer layout for a PCB in our paper from the following link. Thanks.



(Ctrl)

https://learn.sparkfun.com/tutorials/pcb-basics/all

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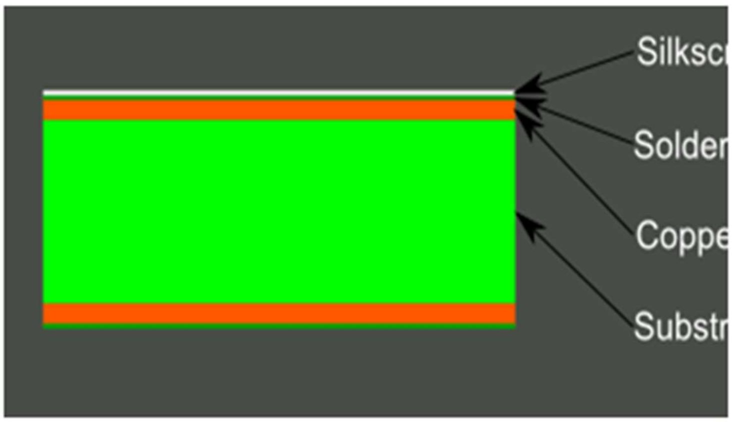

Figure 5.10

Send message

To

Xander Campman

Subject

Permission to use picture for Senior design project

Message

Hello,

I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use the diagram describing LoRa's IOT in our paper from the following link. Thanks.

https://www.researchgate.net/figure/LoRaWAN-network-composed-of-the-end-nodes-any-LoRa-enabled-sensor-node-

Hello,

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Figure 5.8

To RodNave@gsu.edu

Cc

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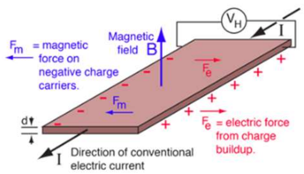
Hello,
I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use a diagram explaining the properties of how an hall effect sensor works in our paper from the following link. Thanks.



http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/Hall.html

Hello,
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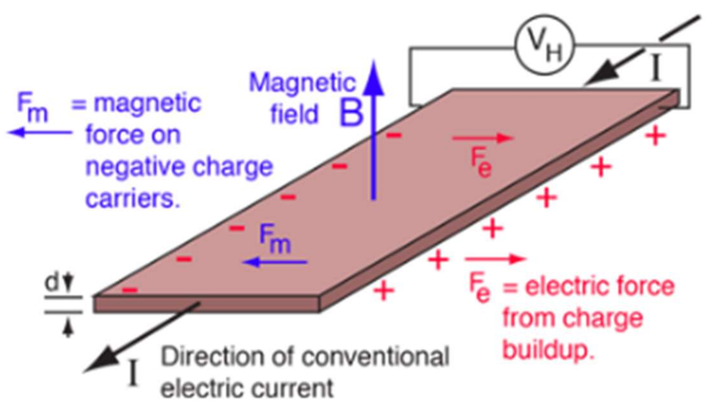
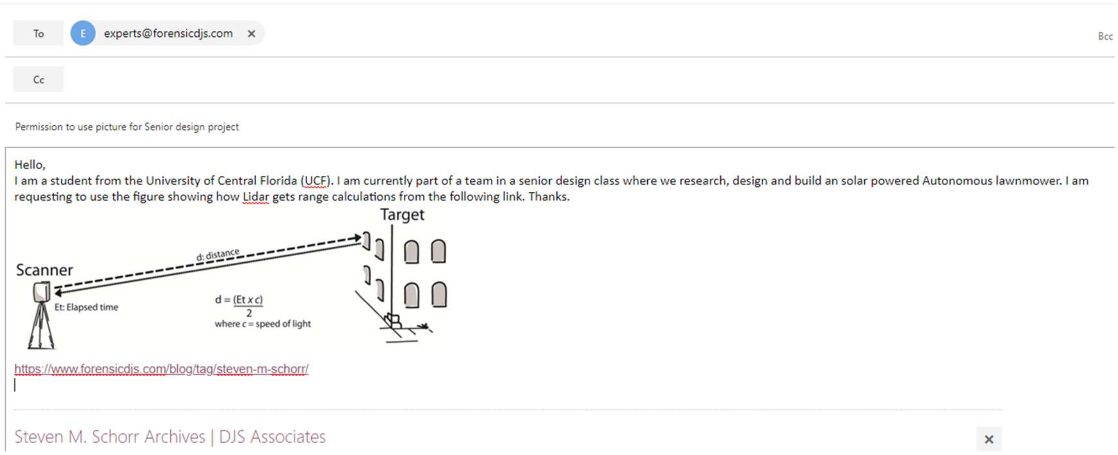


http://hyperphysics.phy-

Figure 5.4



To experts@forensicdjs.com

Cc

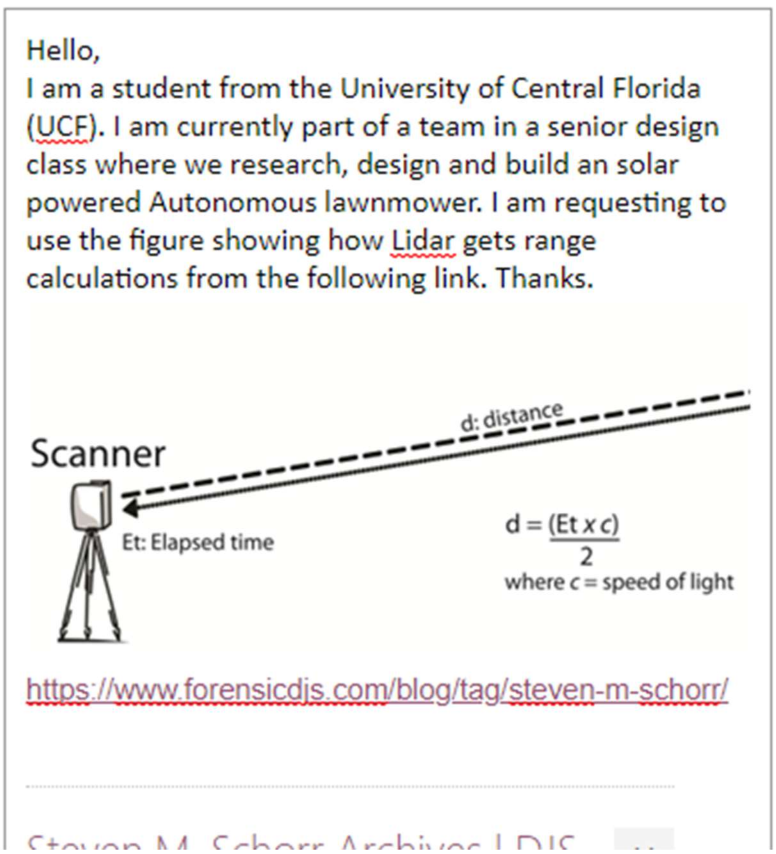
Bcc

Permission to use picture for Senior design project

Hello,
I am a student from the University of Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to use the figure showing how Lidar gets range calculations from the following link. Thanks.

https://www.forensicdjs.com/blog/tag/steven-m-schorr/

Steven M. Schorr Archives | DJS Associates



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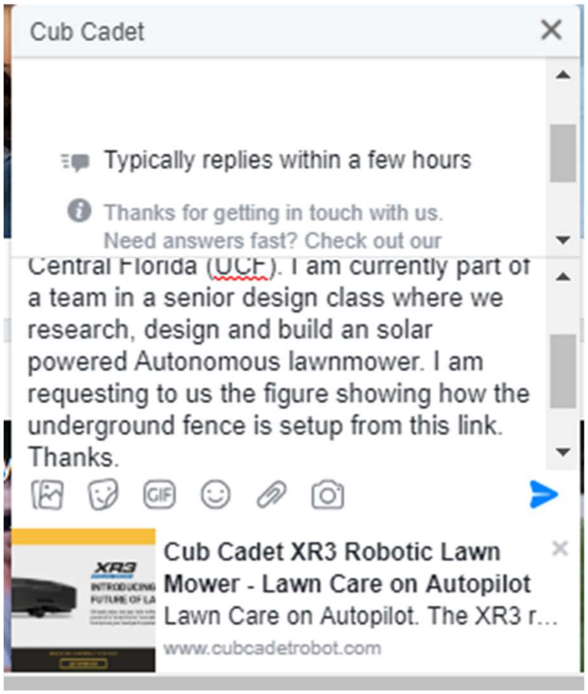
https://www.forensicdjs.com/blog/tag/steven-m-schorr/

Figure 5.7


Cub Cadet
Typically replies within a few hours
Thanks for getting in touch with us.
Need answers fast? Check out our
Central Florida (UCF). I am currently part of a team in a senior design class where we research, design and build an solar powered Autonomous lawnmower. I am requesting to us the figure showing how the underground fence is setup from this link. Thanks.
Cub Cadet XR3 Robotic Lawn Mower - Lawn Care on Autopilot
Lawn Care on Autopilot. The XR3 r…
www.cubcadetrobot.com