BEAM

Botanical Eradication and Management Machine

EEL 4914 | Senior Design I | Summer 2024 | Group 1

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Chapter 2 – Project Description

2.1 Background

The agriculture industry and all related industries in the US accounts for approximately the 5.6% of the Gross Domestic Product (GDP) and 10.34% of U.S employment [1]. Although, its significance might not seem much, production agriculture is the leading source of economic activity in numerous counties spread throughout the country, but they concentrate in the Great Plains states towards the Midwest. The Midwest is renowned for fertile soil, a temperate climate, and plenty of water resources like rivers and aquifers which are essential for irrigation and sustaining crop growth [2]. With our project, we aim to aid in the crop production yield of farms to fight the loss of direct employment and lower than average wage in rural areas, and to make it easier for farmers, both big and small, to diversify their production since research show that it has a direct correlation with a decrease in population [3].

In agriculture, one of the the largest inhibitors of plant growth are weeds. Weeds are plants that grow in places humans don't want them to grow. These invasive plants can spread rapidly through fields, becoming very tedious and difficult to remove. Weeds will often grow "too well", and outcompete desired crops for nutrients, water, and sunlight [4]. This can cause great economic loss for a farm. Monitoring and controlling weed growth can greatly benefit commercial crops, and there are only a few ways to handle this problem. So far, the strategies most used by commercial farmers are manual weeding, which is paying workers to pull weeds, mechanical weeding, using a machine pulled by a tractor to uproot weeds, or chemical weeding, using pesticides to kill weeds [5].

Chemical herbicides are one of the most common tools used to remove weeds, but along with the benefits of weed removal come disadvantages from their toxicity to the environment and human health. These herbicides can be extremely toxic to livestock, fisheries, natural predators, soil microbiomes, native plants, crops, and humans [6]. The many disadvantages of chemical herbicides should outweigh the benefits, but it is still a popular technique in many countries. Our project aims to revolutionize weed removal through a combination of object recognition and lasers. The use of light radiation to burn weeds is more environmentally friendly and will promote overall crop health, prevent the destruction of soil and water microbiomes, and decrease human contact with toxic chemicals.

2.2 Goals/Objectives

The goal of our project is to build a solar-powered vehicle-type robot that uses object detection to recognize weeds and then uses a laser to remove them. Some of the main goals and objectives are listed below.

Overall Goals

- Build a robot to navigate a field.
- Build a laser system capable of burning plant material.

Robot Objectives

- Be able to navigate a field without getting stuck or becoming lost.

- Be able to charge battery using sunlight.

Laser System Objectives

- Achieve a high-power output from the laser diode to ensure efficient moisture evaporation, allowing for quick and effective weed control.
- Design the system to be lightweight, compact, and portable to be equipped with the robot, allowing it to navigate various terrains and locations with ease.
- Integrate safety features into the robot's design to prevent accidents and ensure safe operation in proximity to humans and other objects.

Stretch Goals

- Create an application with a user-friendly GUI used to monitor the robot's progress.
- Have a reasonable data refresh rate for the application.

2.2.1 Hardware

2.2.1.1 Laser Robot – Basic Goal:

Our project's overall engineering goal is to find and identify weeds using a vehicle robot that can navigate its surroundings without becoming lost or stuck. To obtain accurate identifications, we plan to feed our object detection system many images to compare real plants to. The data we use to train the system will be essential for correct identifications of crops vs weeds. The navigation system will use SLAM based mapping so that it does not get lost and wander aimlessly. We will use a lidar system to map out the area and use coding logic to help the robot make navigation decisions. The start-up method we want to use for the robot will be having it map out the entire area, and then it will proceed to start identifying weeds and note treated locations. It is also essential that our robot does not become stuck in the wet soil while navigating its area. It will be designed for moderate to mild conditions, and not built for extremely muddy conditions. This is to protect the hardware. The robot will be water resistant, but it will not be built to withstand rainy and wet conditions such as being left out in a storm. To ensure that our robot does not become stuck in the soil or mud, we will equip the chassis with quality tires and strong motors.

An advanced goal of our project is to create a 3D active map model of the area the robot is in. This will not only help with navigation but allow for path planning and accurate location tracking for weed treatments. The 3D active map will allow for enhanced spatial awareness like obstacle detection and depth perception. This is important on a farm plot with uneven surfaces and crops in the way. Using simultaneous localization and mapping (SLAM) techniques, our robot will be able to build and update maps in real-time while monitoring its location. This will allow for improved route planning, and adaptability for changes in the environment such as terrain changes or moving objects.

2.2.2 Software

2.2.2.1 Basic Goals

This application would let users navigate a graphical user interface allowing for easy user interaction between menus and systems. Additionally, the application will allow for real time monitoring to allow the user to track the robot in action. The application should allow for a reliable communication link between the robot and itself, allowing the user to momentarily take tele-present control remotely move the robot.

2.2.2.2 Stretch Goals

An application for the robot would let users monitor the progress of weed removal in their field and document weed location so the user would know where problem areas are located. It would also show battery life and current location of the robot. The app would increase the amount of data provided to the user about their field, allowing them to make more informed choices about how to provide proper care for crops.

2.3 Description of Features and Functionalities

2.3.1 Navigation

LiDAR technique will be used to help the robot navigate by emitting laser pulses to create detailed 3D maps of their surroundings. This enables accurate environmental mapping, obstacle detection, and avoidance. The technique supports simultaneous localization and mapping. Allowing the robot to track its position while building maps. LiDAR data facilitates efficient path planning and dynamic path adjustments in real-time, ensuring safe and autonomous navigation in both indoor and outdoor settings.

2.3.2 Rechargeable Power System

Our outdoor robot is powered by a solar-charged power system, featuring solar panels connected to a high-capacity battery. Designed for field operations, this system uses solar energy to keep the robot charged and operational throughout the day, ensuring continuous performance without the need for external power sources or overnight charging.

2.3.3 Weed Detection

The weed detection process begins with high-resolution cameras mounted on the robot capturing images of the field. These images are then processed using machine learning algorithms to identify weeds based on their visual characteristics. Machine learning models trained on weed and crop datasets classify the objects in the images. Weeds are identified by their size, shape, color, texture, and other features. Once the weeds are detected, their positions are calculated relative to the robot's location. This information is used to precisely target and activate the laser beam onto the detected weeds for effective weed-killing. By utilizing cameras and machine learning algorithms, the robot can accurately detect weeds in real-time, enabling targeted weed control without harming surrounding plants.

2.3.3 Weed Elimination

To eliminate weeds effectively, we are going to use laser diodes to evaporate the plant moisture. A lot of studies and experiments have been done on elimination of weeds by cutting their stems using lasers, but Mathiassen et al. [7] introduced another way to eradicate weeds by increasing the temperature of the moisture in the plant cells to eventually delay or stop its growth.

2.3.4 Light Source

Lasers are considered one of the most effective light sources for targeting weeds [8]. Laser is an acronym for "light amplification by stimulated emission of radiation," which refers to a device that emits light through the optical amplification process, which is based on the stimulated emission of electromagnetic radiation. Different types of lasers use different active (laser) media emitting at various wavelengths [9]. CO2 lasers demand high voltage and current and need a separate cooling system when operated outdoors, resulting in complicated installment. On the other hand, fiber lasers are the most powerful while most costly. For this project, we are going to use diode lasers since they are not only portable and easily achievable but also affordable since they require low voltage and current compared to other types of lasers. Overall, the distinctive size, weight, and cost, along with their high efficiency and reliability of diode lasers make them more convenient to incorporate into systems. Another important aspect of using a laser diode in this project is its narrow beam, which minimizes effects on soil health and non-target organisms. This reduces interference with other crop activities and helps preserve beneficial organisms [8]. For the proof of concept, laser diodes with three different colors (blue, red, and green) will be used to test and compare. In order for laser diodes to enhance the efficiency of a robot in field operations, treatment duration should be minimized. An experiment was conducted on two types of weeds growing in the pots that underwent laser treatment using laser diodes placed approximately 5 cm away and perpendicular to the weed stems to minimize the treatment time. This experiment followed a factorial design involving 2 laser output powers, 3 treatment durations, and 2 weed species, resulting in a total of 12 treatments. Each treatment combination was replicated 5 times. The laser powers were 5.1 W and 6.1 W, respectively, while treatment durations varied between 0.5, 1, and 1.5 seconds. As a result the 5.1 W diode laser showed an overall effectiveness of 66.67% (kill/stunt) across all treatment durations. On the other hand, the 6.1 W diode laser exhibited 80% effectiveness for treatment durations of 0.5 s and 1 s, and 100% effectiveness for the 1.5 s duration [8]. This experiment presents a direct relationship between laser power and treatment time. Applying the experimental findings to our project, we intend to utilize a high-power laser while minimizing treatment duration. However, considering laser safety concerns, it's crucial to note that when a laser beam contacts a surface, it converts into heat energy. High-energy lasers have the potential to ignite materials and inflict thermal injuries [10]. Employing diode lasers with lower output power has fewer operational risks compared to high-powered CO2 and fiber lasers, which are more complex. However, even low-output diode lasers can pose risks to the eyes upon exposure, necessitating the use of protective eyewear [10]. Therefore, we plan to still maintain high laser power and low treatment intensity while ensuring optimal safety measures.

2.3.5 Beam Collimator

The beam collimator is a key component within the weed-killing robot's optical system, responsible for aligning and focusing laser beams emitted by the red, blue, and green laser diodes. Its main function is to ensure these laser beams are parallel and accurately directed toward target weeds, optimizing weed elimination efficiency. With adjustable collimation angles, the collimator fine-tunes the laser beams' divergence characteristics to match each diode, maximizing energy delivery. Constructed from high-quality optical materials like glass or acrylic, the collimator features anti-reflective coatings on its lenses, minimizing energy losses due to reflection and improving laser beam transmission efficiency. This design guarantees a significant portion of laser energy reaches the target weeds, enhancing weed-killing effectiveness. Its compact design allows easy integration into the robot's optical setup, offering versatility in mounting options while maintaining durability for field operations. Installation and alignment of the collimator are straightforward, enabling swift setup and adjustment on-site. Its compatibility with other components, such as galvanometer mirrors, ensures seamless integration into the robot's optical system, enhancing precision targeting capabilities.

2.3.6 Galvanometer Mirrors

The galvanometer mirrors will be used to precisely direct the combined laser beam toward the detected weeds. Equipped with high-speed motors, these mirrors swiftly adjust to target the weeds identified by the camera system, ensuring accurate and efficient weed elimination. With specifications tailored for the project's needs, such as high angular resolution and rapid response times, the galvanometer mirrors offer precise control over the laser beam's direction. Their compatibility with the robot's control system allows seamless integration, facilitating real-time adjustments for optimal targeting. Additionally, their durable construction ensures reliability in various environmental conditions, making them indispensable for precise and effective weed-killing.

2.3.7 Smartphone Application

The application will provide users more information about weed treatment and problem areas in their field. This application will be hosted on a web interface that runs on a webserver. This server will allow the user to control the raspberry pi’s GPIO pins and read information from sensors from a web browser. The code to read the data from the robot’s external sensors will be read through a Python script interacting with the MCU. This information will then be displayed on the webserver through a user interface written in Java or HTML.

2.4 Block Diagrams

2.4.1 Hardware

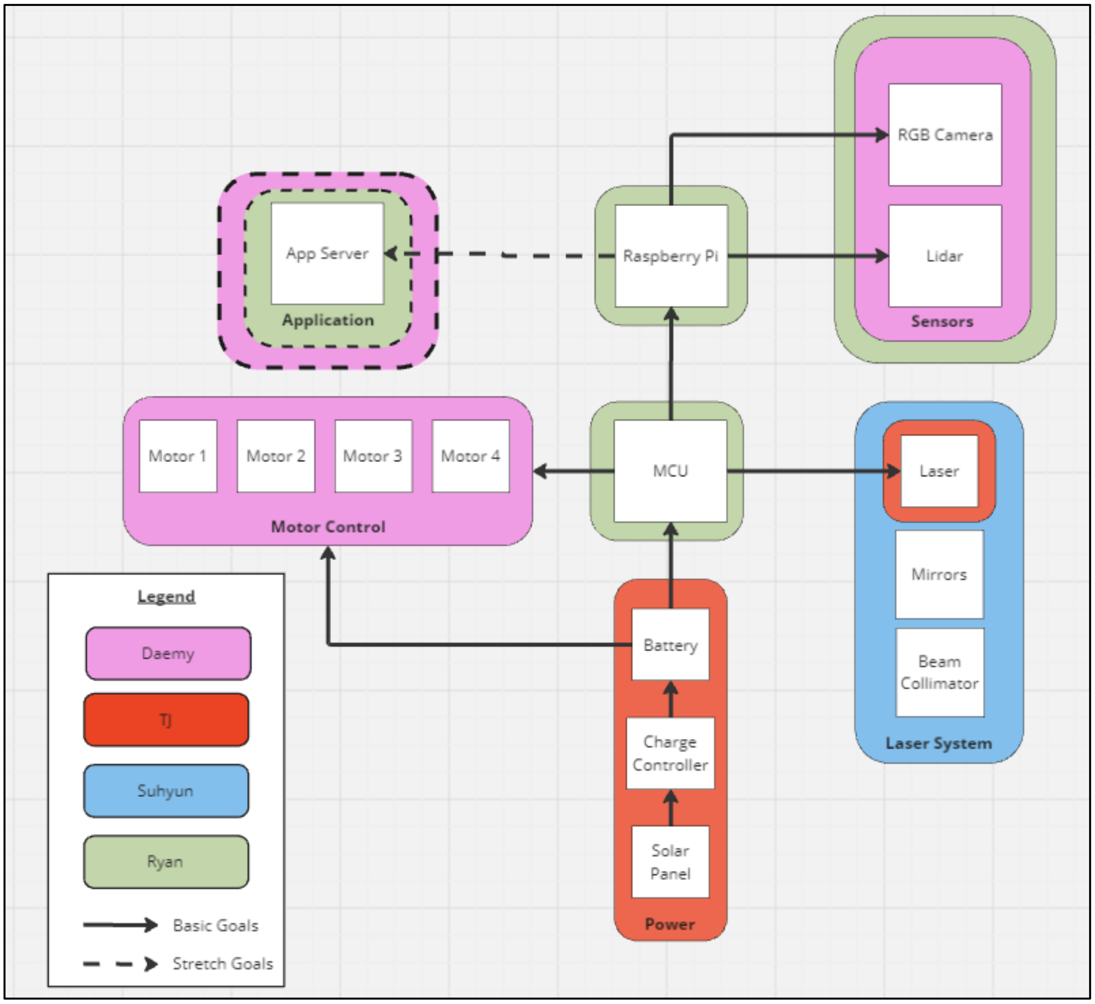


Figure 1. Hardware block diagram

2.4.2 Software

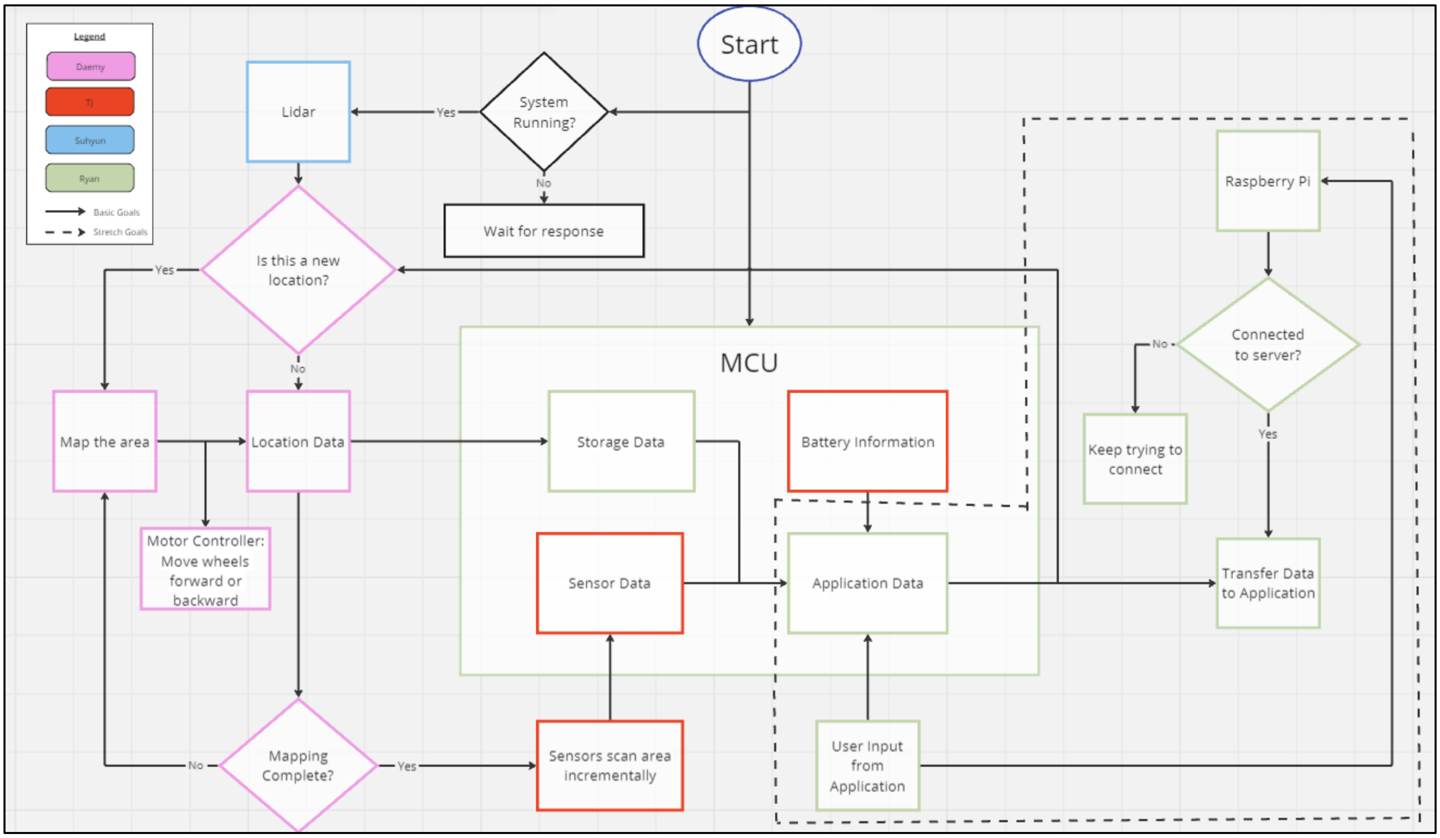


Figure 2. Software Block Diagram

2.5 Engineering Requirements Specifications

Demonstratable specifications are highlighted in yellow.

BEAM	
Chassis	
Length x width x height	TBD
Weight	TBD
Solar Panel	
Max Power	6 W
Maximum Voltage	12 V
Battery	
Maximum Lifespan	10 h
Maximum Voltage	12 V
Laser Source	
Wavelength Range	450 – 550 nm
Optical Power	1000 – 5500 mW
Application	
Information refresh rate	≤ 5 seconds

Weed Treatment	
Treatment Time	1 – 3 seconds
Treatment Distance (Laser Pointer End to Plant)	5 – 10 cm
Efficiency	Expected at 70-85%

Table 1. Engineering Specifications

Marketing Requirements
1. The Rover should not exceed the proposed object (not including replacements).
2. The Rover should accurately identify weeds.
3. The Rover should be easy to use.
4. The Rover should withstand weather changes.
5. The Rover should have low maintenance.
6. The Rover should have high performance.
7. The Rover should have moderate power consumption.

Table 2. Marketing Requirements

2.6 Past and Existing Projects' Comparison

Previously existing products and related work, like our project, include:

Carbon Robotics is a leading organization within the agricultural technology industry. Their particular niche is laser weeding technology. Their autonomous robot weeder is diesel-powered and equipped with multiple high-resolution cameras and an AI-powered computer to aid in autonomous features. The robot is estimated to eliminate around 200,000 weeds per hour without disrupting the soil. [11]

EcoRobotix is a Swiss corporation that has developed a solar-powered weeding robot that uses cameras and GPS guidance to navigate and detect weeds. Instead of a laser, the robot targets and applies microdoses of herbicides to the individual identified weeds. The idea is to use these precisely targeted microdoses to significantly reduce overall chemical usage. This robot adapts its operation speed to the size of the field it is working on as well as the overall weed density in a given area, allowing it to remain power-efficient in most situations. [12]

LettuceBot, created by Blue River Technology, uses computer vision and image recognition to identify weeds and spray them with a precision dose of herbicide. The idea is similar to that of the EcoRobotix robot, if the weeds can be found much easier and sprayed with much higher precision with much less use of these herbicides, reducing the overall impact over time. [13]

WeedBot, based in Lavata, is planning to launch its own laser weeding robots. These aim to provide a less harmful alternative to traditional herbicides, offering precise weed control using an AI-backed algorithm for weed and crop recognition. After detection, the weeds are quickly eliminated with minimal disruption of other organic material and soil. [14]

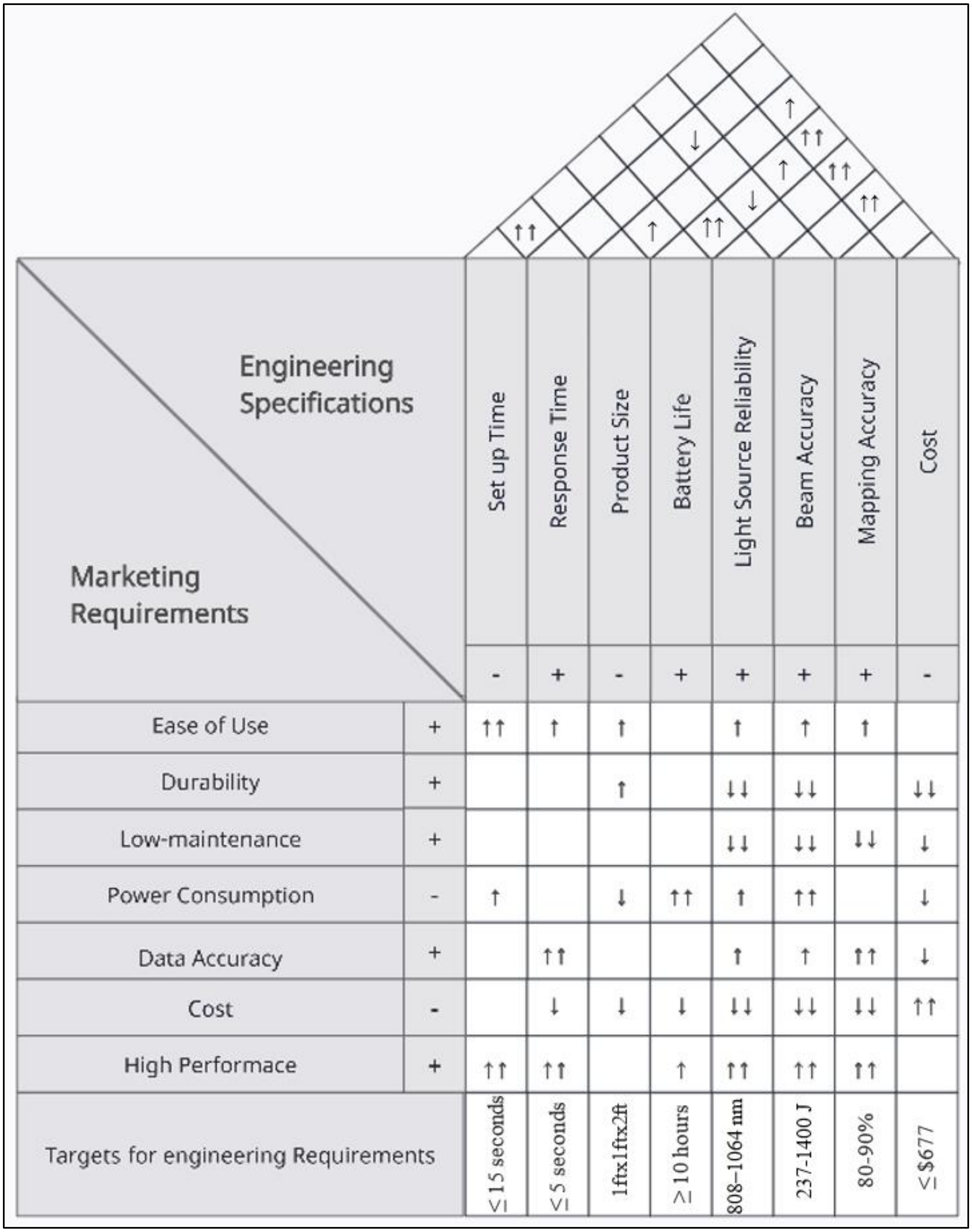
Autonomous Diode Laser Weeding Robot, A project led by the West Central Research and Outreach Center collaborated with the University of Minnesota to develop a laser weeding robot designed specifically for use in cotton fields and to utilize deep learning for weed detection. Combining a GPS-based navigation system with visual serving allows the robot to precisely target and eliminate weeds using diode lasers. Another project aims to reduce the reliance on chemical herbicides as well as improve overall sustainability. [15]

2.7 House of Quality

The house of quality takes the information from the engineering requirements (Table 1) and the marketing requirements (Table 2) from the section 2.5 and provides matrices of correlation between them. Below there's a legend that describes what each correlation means and their polarity.

Correlation Matrix	
↑↑	Strong Positive
↑	Positive
↓	Negative
↓↓	Strong Negative
	Not Correlated

Positive Polarity	+
Negative Polarity	-



Chapter 10 – Administrative Content

10.1 Budget and Financing

Basic Budget:

Item	Description	Quantity of item	Estimated Cost	Total Cost
LiDAR System [16]	LiDAR System	1	$40	$40
Blue Laser Diode [17]	Wavelength: 455 nm Optical Power: 5000 mW	1	$42	$42
Red Laser Diode [18]	Wavelength: 639 nm Optical Power: 2100 mW	1	$90	$90
Green Laser Diode [19]	Wavelength: 530 nm Optical Power: 1650 mW	1	$150	$150
Chassis and Motors: DIY and Pre-Assembled [20] [21]	DIY and Pre-Assembled Chassis and Motors	2 + 1	$27 + $24	$78
Microcontroller and Sensors [22]	Raspberry Pi and Arduino with sensors	2	$80	$160
Battery and Power Management [23]	Battery and power management components	1	$37	$37

Miscellaneous Components [24]	Electronic components kit	1	$30	$30
Solar Panel [25]	Solar panel + charge controller	2	$25	$50

Total Overall Cost: $677

10.2 Project Milestones

10.2.1 Senior Design I

Week	Date	Milestone Description
1	5/13/24 – 5/19/24	Form group project and storm ideas.
2	5/20/24 – 5/26/24	Choose a project idea and start the D&C Report.
3	5/27/24 – 6/2/24	Finish the first draft of D&C 10-page Report.
		Submit Bootcamp Assignment.
		Work on the group website.
4	6/3/24 – 6/9/24	Attend the D&C Group meeting.
		Start the updated version of D&C Report after meeting with professors.
5	6/10/24 – 6/16/24	Submit updated version of D&C Report to the website (20-page minimum).
6	6/17/24 – 6/23/24	Start the 60-page Report.
		Assignment on Standards
7	6/24/24 – 6/30/24	Finalize the 60-page Report
		Finish Quiz A to G.
8	7/1/24 – 7/7/24	Upload the 60-page Report. (Preferably more than 60 pages).
9	7/8/24 – 7/14/24	Attend the 60-page Report Group Meeting
		Start working on the updated version of the 60-page Report.
		Submit the updated 60-page Report onto group website
10	7/15/24 – 7/21/24	Order parts

		Work the Final draft of the Project Report.
11	7/22/24 – 7/23/24	Submit the SD I Final Report

10.2.2 Senior Design II

Week	Date	Project Milestone
1	8/19/24 – 8/25/24	Order remaining parts
2	8/26/24 – 9/1/24	Start testing individual components functionalities.
3	9/2/24 – 9/8/24	Start the design of the App.
4	9/9/24 – 9/15/24	Finish Power functionalities
5	9/16/24 – 9/22/24	Finish Motor control
6	9/23/24 – 9/29/24	Finish Sensor functionalities
7	9/30/24 – 10/6/24	Finish connecting all code in MCU
8	10/7/24 – 10/13/24	Assemble hardware
9	10/14/24 – 10/20/24	Meet with professors
10	10/21/24 – 10/27/24	Redesign if needed
11	10/28/24 – 11/3/24	Finish App
12	11/4/24 – 11/10/24	Test app functionality
13	11/11/24 – 11/17/24	Finish final prototype
14	11/18/24 – 11/24/24	Test final prototype
		Record Demo
15	11/25/24 – 12/1/24	Finalize and submit Final Report
16	12/2/24 – 12/7/24	Live Demo

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