Automatic Weeding Arm

Spring 2020 ECE 445 Senior Design

Project Proposal

Team 9

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1 Introduction

1.1 Objective

For generations, humans have used manual labor to curb aggressive weeds, which leech nutrients and resources from staple crops. As agricultural demands and farm sizes grew, the industry started to heavily rely on chemical herbicides to ensure maximum yields. Herbicide use, however, has not been as harmless as originally believed. Long term exposure to chemical runoffs has been linked to kidney, liver and spleen complications in humans [1]. Scientific developments have also shown that the most commonly used herbicide contributes to a host of developmental problems in pregnancies, leading to disruption of sex hormones and even miscarriages [2]. Still, it is hard for the agricultural industry to part with this practice, as there are no fully chemical-free alternatives that work as efficiently. To reduce herbicide use in crops, we propose a solution of an automatic robotic weeding arm that can identify post-emergent weeds and cut them with an attached blunted shear. Automated weeders do exist in the industry, but they still rely on herbicides and just promise localized exposure [3]. This does not mitigate the risks of the herbicides themselves as repeated exposure to these specific chemicals is still harmful. Since there are existing agricultural robots in the market that can navigate the difficult terrain of crop fields, such as the TerraSentia [4], we are not focusing on the robotic base. Rather, we see the arm as a potential extension of a robotic base, allowing us to target the specific problem of chemical-free weed removal.

Our arm focuses on the identification of various seedling species and automation of the weeding process. The arm is fitted with a camera that can not only detect different seedlings through neural network training but also enables real-time video monitoring from a connected computer screen. Once the arm can detect the unwanted plant, it can maneuver and cut the weed with its motorized shear. We decided to cut instead of pull the weeds because cutting requires less force and it is more efficient when treating tall plants. To accomplish this function, the arm will have 4 motorized joints with 180 degrees of freedom, allowing the arm to trim weeds on either side. The flexibility of the arm allows it to attack hard-to-reach plants effectively. Due to the arm's trainability, it can also be easily repurposed to perform many different agricultural functions. For example, once the arm can learn from various plant databases, it could easily be used to pick fruit or trim foliage just by switching out the shear-hand attachment for other applicable tools.

1.2 Background

Weed control through herbicide has recently become controversial for its carcinogenic potential [5] and environmental-contamination concerns [6]. Currently, farms use about 44 gallons of herbicide per acre to kill unwanted weeds [7]. This practice comes with risks. Runoff from the herbicide sprays threatens the natural ecosystem through the groundwater and soil. Herbicide use has also affected human lives, as research has linked an increase in cancer with the use of glyphosate, a popular weed killer used in the industry [5]. In terms of economics, chemical crop control has been slowly bleeding farmers dry. Agrochemical companies have been selling genetically modified seeds that can resist the herbicide, but this action only boosts their herbicide sales over time as weeds have evolved into "superweeds" which require higher and stronger doses of chemicals to kill [8]. This ballooning effect can be clearly noted in the soy industry, where, as of 2008, 92% of soy plants had become glyphosate-resistant [9], requiring the industry to begin using genetically modified crops with herbicide and liquid herbicide in tandem. Meanwhile, agrochemical companies have quietly quintupled their prices for both genetically modified seeds and chemical herbicide within the last two decades [10]. Ethically, herbicide use must be phased out, but regressing to the use of human labor is not a realistic solution. Modern agriculture needs a way to streamline the repetitive act of finding and destroying specific plants while keeping the desired crops safe and healthy. Naturally, robotics can provide an answer which is both ethical and cost-effective in the long run.

1.3 High-Level Requirements

- The camera, assisted by a neural network model, can successfully detect and differentiate weeds from other crop seedlings, with a classification accuracy over 75%.
- Camera and ultrasound sensors can successfully locate the location of weeds with respect to the ground and homing location, within error ± 2cm.
- The robotic arm can successfully cut off the weeds (2-12 inches) through the flexible yet torque-sufficient motors, with an over 75% successful rate.

2 Design

2.1 Physical Design

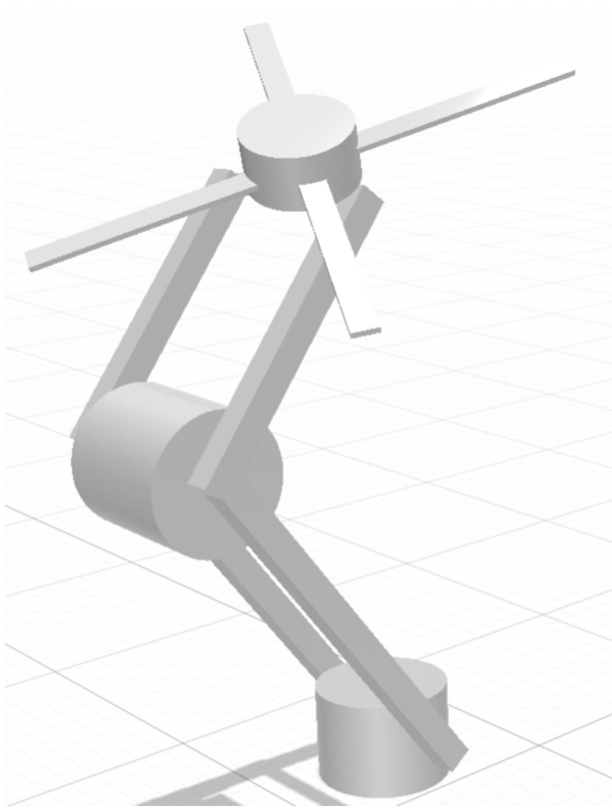

Figure 1: Physical Design

2.2 Block Diagram

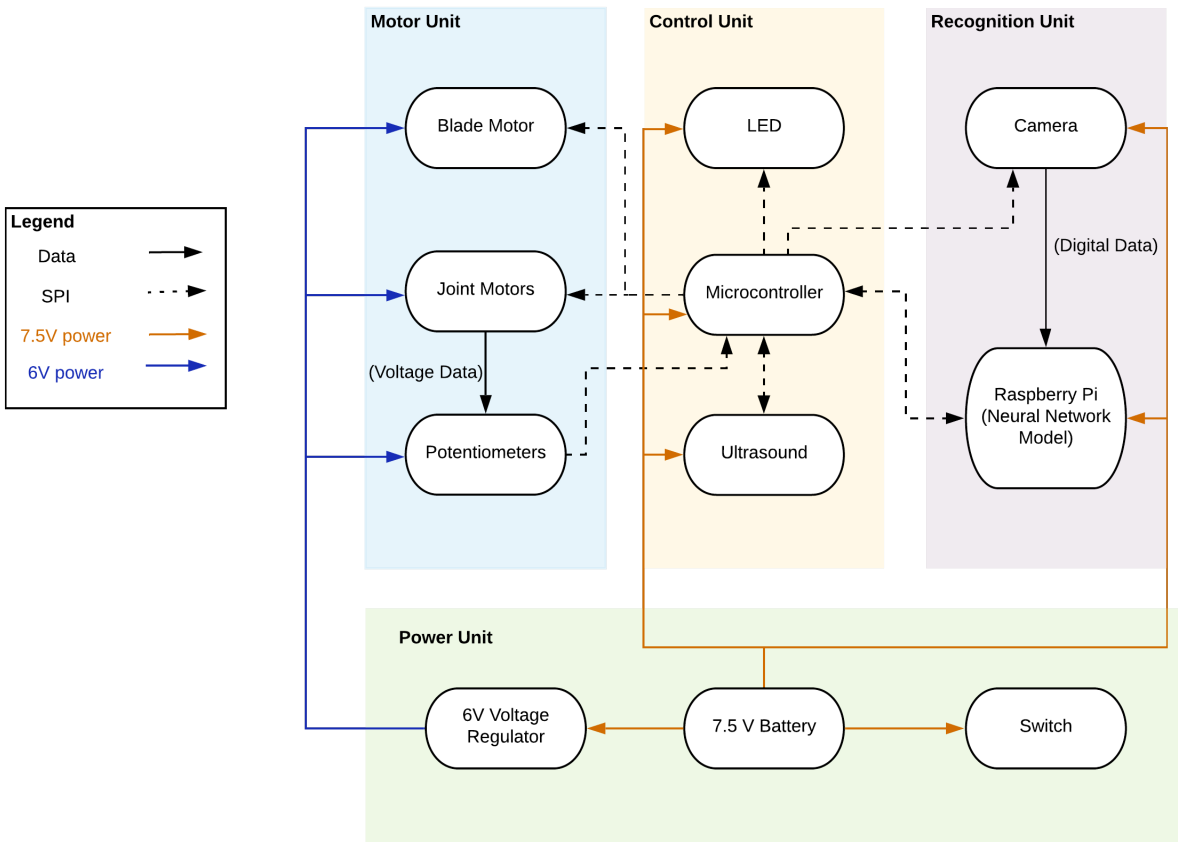

Figure 2: High-level Block Diagram

2.3 Functional Overview and Block Descriptions

2.3.1 Control Unit

1. **Microcontroller**

   A microcontroller can be used to control the four motors utilized in the three joints and automatic shears. We could possibly implement our homing mechanism through microcontroller by utilizing potentiometers.

   Requirement: Microcontroller must be able to communicate with Raspberry Pi and PCB effectively (no bugs, functional) and efficiently (without delay).

2. **Ultrasound**

   We are going to use two HC-SR04 ultrasound modules. The modules can be controlled through Raspberry Pi. The first module will be installed at the bottom of the blade to detect the distance of the arm tip to the ground, as part of our robot's weeding mechanism. The second module will be installed on the top of the blade to detect the distance from the blade to the plant, as the arm tip moves forward to reach the plant.

   Requirement: The ultrasound must be able to detect the distance between ground to arm tip and between blades to plant, and to communicate with Raspberry Pi efficiently to avoid crashing and mislocation.

3. **LED**

   We are going to use one LED to indicate the status of the arm. For example, when weeds are not detected, the LED does not light up. When weeds are detected, the LED lights up.

   Requirement: There is no specific requirement for the type of LED. The LED will light up if weeds are detected. It will do nothing if no weed is detected.

2.3.2 Recognition Unit

1. **Camera**

   An Arducam 5MP OV5647 Raspberry Pi camera module with motorized focus is connected to the Raspberry Pi series board for image detection and real-time video monitoring.

   Requirement: The camera must be compatible with Raspberry Pi 3B+ to capture clear images and accomplish video streaming.

2. **Raspberry Pi Board**

   Raspberry Pi 3B+ will control the camera module and ultrasound unit, communicate with the microcontroller and allow us to record test runs and review them at a later time.

   Requirement: The Raspberry Pi must successfully receive digital data from the camera within a delay of 3 seconds to appropriately detect the weeds. And it must connect to the microcontroller which oversees the physical controls.

3. **Neural Network**

   The neural net model is responsible for detecting and differentiating weeds from other crop seedlings. The training dataset will be mainly based on the V2 Plant Seedlings Dataset [11] and Weed Detection in Soybean Crops [12] from Kaggle, which contains images of crop and weed seedlings at different growth stages. We will expand the dataset by adding images taken by the camera module.

   Requirement: The baseline for the complexity of the neural net model is 2-layer, which can be increased based on accuracy. The neural network must be able to detect weeds from other crops with an over 75% accuracy through training the crop seedling datasets.

2.3.3 Power Unit

1. **7.5 Volt Battery**

   The battery powers the full system directly except for the motor unit. It will be connected to a voltage regulator, and the voltage will be drawn, regulated, and used to power the motor unit indirectly. We plan on using a rechargeable lithium battery, as this will be sustainable and allow us to repeatedly test our device.

   Requirement: The battery should be able to distribute 7.5V power to the control and recognition units and to the voltage regulator.

2. **6 Volt Voltage Regulator**

   The Voltage Regulator is to power the motor block which runs at a lower voltage. This setup allows us to have a localized power unit.

   Requirement: The voltage regulator should be able to distribute 6V power to all motors and potentiometers.

3. **Switch**

   The switch will be used to turn the robotic system on/off, giving us an overall control when testing.

Requirement: The switch is functional to turn on/off the whole system without any delay.

2.3.4 Motor Unit

1. **Joint Motors**

   Three MG995 servo motors (4.8-7V) with stall torque 12-13kg/cm will be used at the joints. The controlled rotation is 180 degrees (90 on each dimension), providing enough flexibility for the joints. The motors will be controlled through the microcontroller to achieve designed positioning when operated.

   Requirement: The motors must be controlled such that three joints together can conduct designed motions, i.e., move, and rotate 180 degrees through the microcontroller.

2. **Blade Motor**

   One more MG995 servo motor (4.8-7V) with the specifications listed above will be used to control a blade of the shear. It will be able to maneuver the lower blade up and down, to create a controlled snipping motion. This will be used to trim the weeds detected by the Recognition Unit.

   Requirement: The motor must be controlled via the microcontroller so that it can carefully snip the identified weed with the proper force and velocity.

3. **Potentiometer**

   To make the robotic arm return to the home position, we are planning to include four potentiometers [13]. They will be mounted on a microcontroller, as we found it is more efficient in terms of positioning and speed of feedback. The potentiometers will be controlled by the microcontroller. They will be each connected to a motor, as voltage signals need to be collected to determine the position of the arm.

   Requirement: The potentiometer is functional as it delivers location information through a microcontroller, allowing us to work with homing and cut positioning.

2.4 Risk Analysis

We foresee some functional problems with the real-time monitoring system as the Raspberry Pi camera is known to be slow to process and synchronize. We might experience some delays and lagging, which would not allow us to monitor the robot's behavior as it occurs. However, this delay could fall under an acceptable tolerance as there are no drastic negative consequences from this risk.

Other functional risks lie in the execution of the movement, which needs to be precise to achieve the arm's cutting function. First, the weed's detection is achieved by recognizing weed species on the focal plane of the camera. Then, the arm moves forward a distance which equals to focal-plane distance. In this process, motion-location inaccuracy may occur due to the physical sizes of components, i.e., blades and robotic body. The speed may be slow, considering the total weight of moving components and the signal transportation from microcontrollers to joints. After the blade is maneuvered next to the weed, it will be lowered until the ultrasound sensor detects the ground to be within 1cm to the blade. Although we plan to design the lowering speed as 1cm/s, the signal should be transmitted fast enough so that the blade does not crash into the ground. Then, the head will rise until no barrier is seen, e.g., stones, ridges, and mounds are not between the blade and the plant. This causes a functional risk that the seedling might be lower than the height of the barrier. In this case, the arm should be readjusted by repeating the step of finding weed in the focal plane, so that it can reach and cut the seedling properly.

Apart from functional risks, there are some hardware risks to be mindful of. Because our design includes many sensors, motors and control boards, i.e., microcontroller, Raspberry Pi and PCB, wiring each component correctly and properly is also a challenge. Issues that might happen include shorting wires, broken sockets or malfunctioning parts. All of these could lead us to debug the circuits for a long time and potentially fail to achieve the project's goal. To avoid unnecessary debugging, we will follow the safety procedure properly, e.g., cutting off the power before rearranging the hardware. We will also prepare extra components in case something is malfunctioning.

From the software side, the challenge lies in balancing the complexity of neural networks and functionality. As a neural network becomes more complex, the identification becomes more accurate, but the required time increases as well. Finding the balance point where the neural network can identify sufficient plant species with acceptable accuracy and the lowest amount of time would be critical to the success of the project.

3 Safety and Ethics

Following the IEEE Code of Ethics #1, we aim "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment." [14]

There are several potential concerns regarding the safety and ethics related to our project. One main safety concern is the usage of rechargeable lithium batteries. The battery is central to the project as it is the main component of the power unit and intends to supply power to all other units. Since our robotic arm is designed to fit an outdoor environment, it needs to function well under direct sunlight and high temperatures. We will carefully check the datasheet of the chosen battery and ensure it is safe to be used in the target environment. In addition, we will follow the safety procedure and conduct circuit implementation and testing in the lab, which is equipped with a fire extinguisher and sand bucket. We will also carefully monitor the battery voltage to avoid over-discharging.

Since the weeding arm is an autonomous system, another potential safety risk is that the system could unexpectedly get out of control and cause damage to the surrounding environment. As indicated by the IEEE Code of Ethics #9, we understand it is our responsibility to "avoid injuring others [and] their properties" [14]. Not only will we carefully check each step when implementing our system, but we will also design a switch particularly for the weeding arm that can stop the whole system immediately in case of any emergency. According to the IEEE Code of Ethics #5, we also strive "to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems." Hence, we would provide a detailed description of our robotic design to all of the users for both safety and education purposes.

Furthermore, blades are important components of the weeding arm to ensure cutting efficiency and efficacy. One safety concern is the blades implemented on the robotic arm. Sharp blades can easily cause accidental cuts if not handled with enough care. To prevent any injuries to the users, we choose to adopt small shears to trim the weeds in our design. The outside of the blades are blunted, and we will ensure only the inside parts of the blades are sharp. This precaution to avoid sharp shears will drastically reduce the risk of accidental cuts.

An ethical concern is the source of data used for the neural net model. In order to obtain a neural net model that can perform accurate detection and classification, we need a relatively large plant seedling dataset for training. While we do not have access to the field to take in plant seedling images to construct our dataset, we will mainly rely on online resources. Based on the IEEE Code of Ethics #5, we will "be honest and realistic in stating claims or estimates based on available data" [14]. We will clearly state the datasets we decide to use for training and honestly report obtained accuracy for classification.

We will only use open-source datasets that are free to share and adapt for non-commercial use. We have checked the license of V2 Plant Seedlings Dataset [12] to be CC BY-SA 4.0 and Weed Detection in Soybean Crops [13] to be CC BY NC 3.0. In addition, we will also carefully examine the permission of any additional data, code, and information before using it. We will ensure "to credit properly the contributions of others" [14] as stated in the IEEE Code of Ethics #7 to avoid violating the code of ethics.

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