GnomerBot: An AI-based Autonomous Weed Detecting Robot

Siddharth Kini

Seminole Science Charter School

February 1, 2020

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Abstract

Weeds growing in a garden are a problem usually dealt with by spraying toxic herbicides. An environmentally friendly, but labor intensive solution is to pull weeds by hand. Automating this task could significantly reduce herbicide use without displacing humans from their jobs. This requires a robot that can accurately detect, travel to and then extract the weed. I decided to focus on solving the first 2 steps- detecting and traveling to the weed.

The goal of the project was to build an AI based autonomous robot to successfully detect and travel to a detected weed 80% of the time.

A machine learning program was trained to detect a certain type of weed. A plant bed was simulated using printed images of common garden plants and the weed to be detected placed in a row. A robotic device with a Raspberry Pi computer and camera feeds real-time images of the simulated garden/plant bed to the weed detection program. Once the weed is detected, the robot targets the location of the weed by checking its position relative to the weed (Left, right or straight ahead.) and heads in that direction. This process is repeated until the robot is aligned with the weed and then travels and stops in front of it.

After conducting my trials, the results showed that the robot successfully traveled to the weed 100% of the time. On average, the robot traveled to the weed under 40 seconds and within 3.6 centimeters to the center of the weed.

Introduction

Weeds are a common problem for gardeners, which are usually dealt with herbicides. However, this is not an environmentally friendly solution. Pulling weeds is a very tiring task. This labor intensive process can be automated, by a robot driven by an AI based weed detection program.

Robots have a multitude of uses and are being utilized in many fields. Robots have made lots of progress in the past two decades. In the past, robots used to have very low mobility, and a small skillset. In addition, these pieces of machinery had a stigma around them that they could be dangerous. However, currently, more and more robots are being used in households around the world. One example are autonomous vacuum cleaners. Currently, many new robots are being built for a wider range of tasks.

Many of these robots employ a programming tool known as artificial intelligence. Artificial intelligence is the idea that a device can be trained to think like a human. One subset of artificial intelligence is machine learning, which uses data to learn and perform complex tasks efficiently. Some examples are voice assistants such as Siri and Alexa. These voice recognition systems learn and adapt to the user's voice and give human-like responses. Google Photos is also another app that can identify similar faces between different pictures.

Machine learning has been used in the past to identify objects. This method could be applied to multiple fields, including agriculture. Could a machine learning program be used to detect a weed in a plant bed and drive a robot to travel to and extract a weed?

Testable Question

How can a robotic device be utilized to detect and extract weeds from a plant bed?

Engineering Goal

Develop and test an AI-based robot that can successfully identify and travel to a detected weed with at least 80% accuracy.

Research

What is Artificial Intelligence?

Artificial intelligence is the idea that a machine can perform human tasks given training. This means that a machine can be given human-like properties which allow them to do tasks that humans have the capability of doing, such as identifying an object as a ball, predicting the stock market, or differentiating a cat from a dog. Artificial intelligence can be gained using many different methods, with machine learning as one of the most popular options.

What is Machine Learning?

Machine learning is a subset of artificial intelligence. Machine learning is a method of data analysis which learns and find patterns from previous data and uses this knowledge to perform a task with little or no human interference. This type of artificial intelligence is used to conduct quality control for products, recognize voices, detect fraud, and many other tasks that may take a human a long time to learn, process and conduct.

What is Object Detection?

Object Detection is where a machine can recognize a given object in an image after training. Object Detection uses machine learning to find similarities in training images, and a given image that the program is being tested on. This type of machine learning is very useful due its wide variety of applications. One of the more recognizable uses of object detection are self-driving cars, which use this technology to detect other cars, pedestrians, and traffic lights.

What Programming Languages can be used for Object Recognition?

There are numerous programming languages that can be used to program AI. In general, many experts agree that python is the best for this application. This is mainly due to its versatility, simple syntax, and fast testing speeds.

How is Artificial Intelligence used in Robotics?

Artificial intelligence is used to program autonomous robots. These robots use pre-programmed instructions to conduct work and make decisions for themselves. Using the technology, robots can travel on their own, conduct activities such as picking things up, and looking around at the world around it.

Materials

- Phase 1: Artificial Intelligence Programming
    - Python
    - OpenCV
    - Camera
- Phase 2: Robotic Device
    - Raspberry Pi 3 Model B
    - Camera
    - Motor Control Board
    - Motors, wheels, chassis
    - Distance Sensor
    - Batteries
    - Breadboard
    - Wire connectors
    - Screws and fasteners
- Phase 3: Testing
    - 4 images of plants
    - 1 image of a weed
    - Poster Board

Procedure

Phase 1: Machine Learning training program

1. Train the Machine Learning program with 'Negative' and 'Positive' images. Negative images do not contain the object to be detected (Weed). Positive images contain a superimposed image of the object to be detected.
2. Write a Weed detection program to use the previously trained 'Machine' to detect the target object. This will activate the camera and begin searching for the target object, a weed. Once detected, the weed will be identified on-screen by a bounding box.
3. Test multiple times to ensure an accuracy of above 70%.

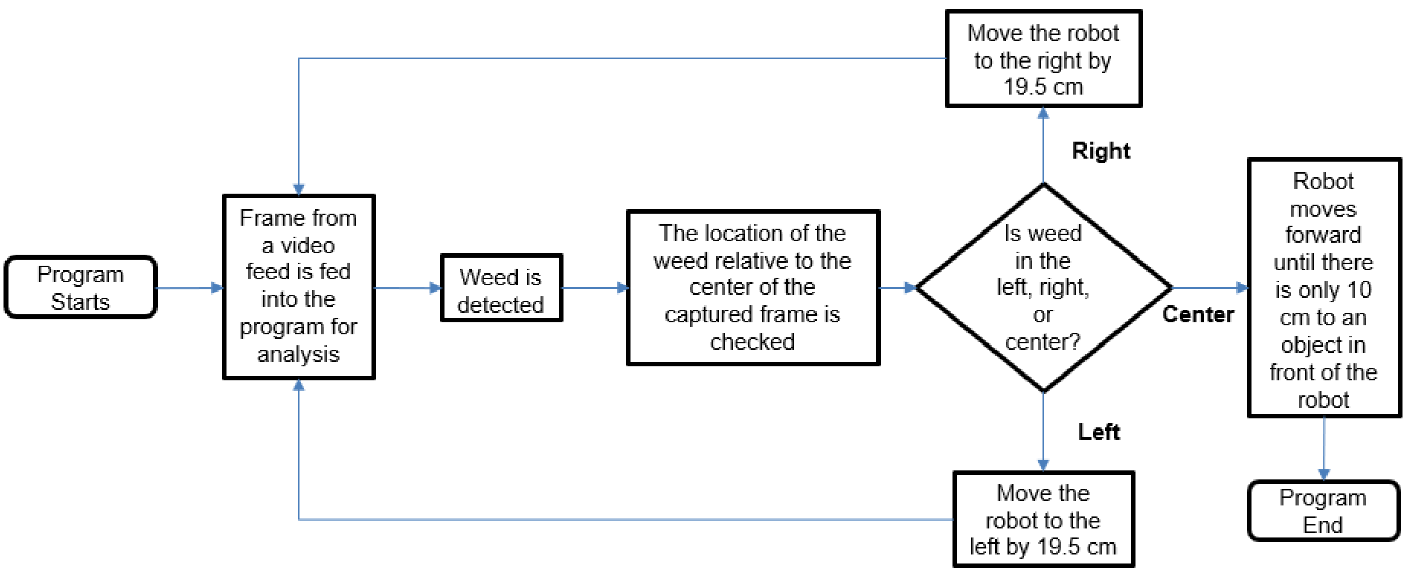
Phase 2: Building the Robotic Device

Step 1: Install software and hardware.

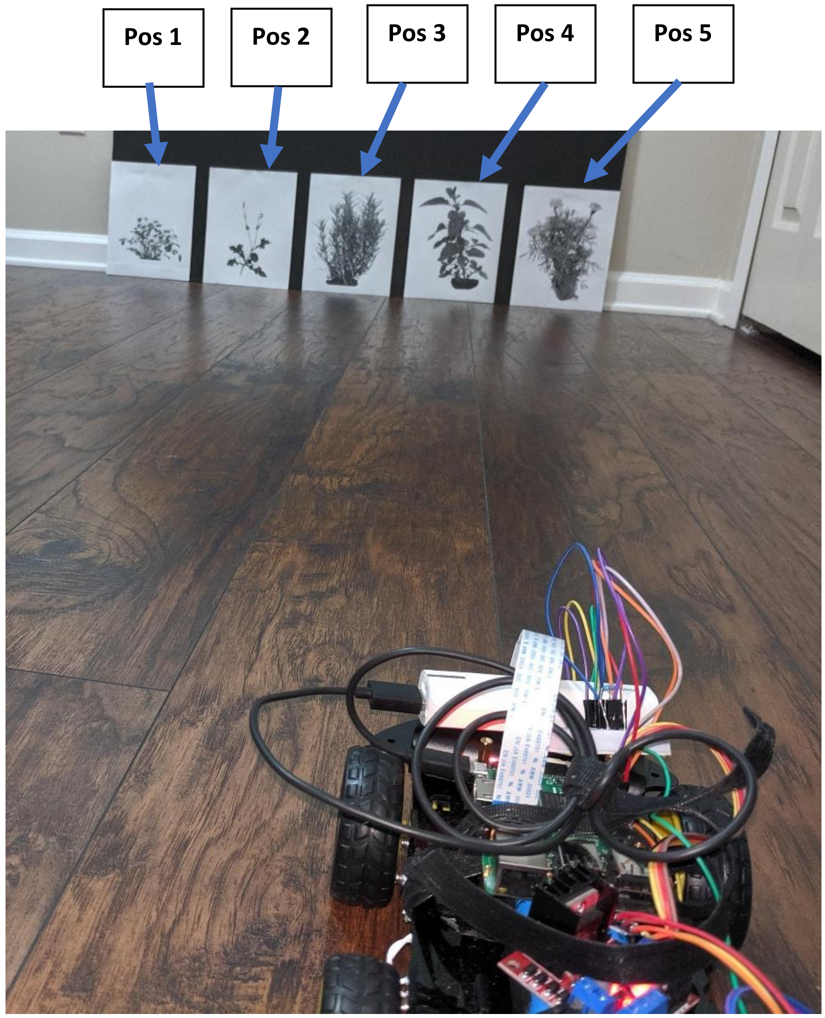
1. Install the ML and detection programs onto the Raspberry Pi.
2. Install the drive motors to the robot chassis and connect its wires to the motor control board.
3. Connect motor control board to GPIO pins on the Raspberry Pi.
4. Attach the distance sensor to the robot chassis and connect it through a breadboard to GPIO pins on the Raspberry Pi.
5. Install the camera on the robot and connect to the Raspberry Pi.
6. Add battery packs to power Raspberry Pi and motor board.

Step 2: Program the robot to steer autonomously.

1. Place the robot in front of the image sample and run the Weed detection program.
2. If a detection is found in the photograph, the program saves the midpoint of the width of the detection as a variable.
3. If the detection is to the left or right of the robot's position, program the robot to turn 90 degrees in that direction, move forward 19.5 cm, and then turn 90 degrees in the opposite direction.
4. If the detection is within a margin of the center of the image, program the robot to move forward until it is 10 cm away from the detected object.



Phase 3: Test the robot



1. Place images of 4 plants and 1 weed on a poster board, with the weed in position 1 (Leftmost).
2. Place the robot in front of the image in position 1, approximately 185 cm away from the board.
3. Run the program.
4. Once the robot stops in front of the weed, measure the distance from the center of the image to the axis of the robot. In addition, record whether the robot correctly identified the weed and the time taken for detection and travel. Take a screenshot of the detection.
5. Reset the robot to the original position but place it in front of the next image to the right.
6. Repeat steps 3 - 5 until the robot has been placed in front of all images.
7. For the next set of images, move the weed to the next position to the right. Randomize the positions of the other plants.
8. Repeat steps 3-8 until the weed has been placed in all five different positions.

Image Sets and Sample Detections

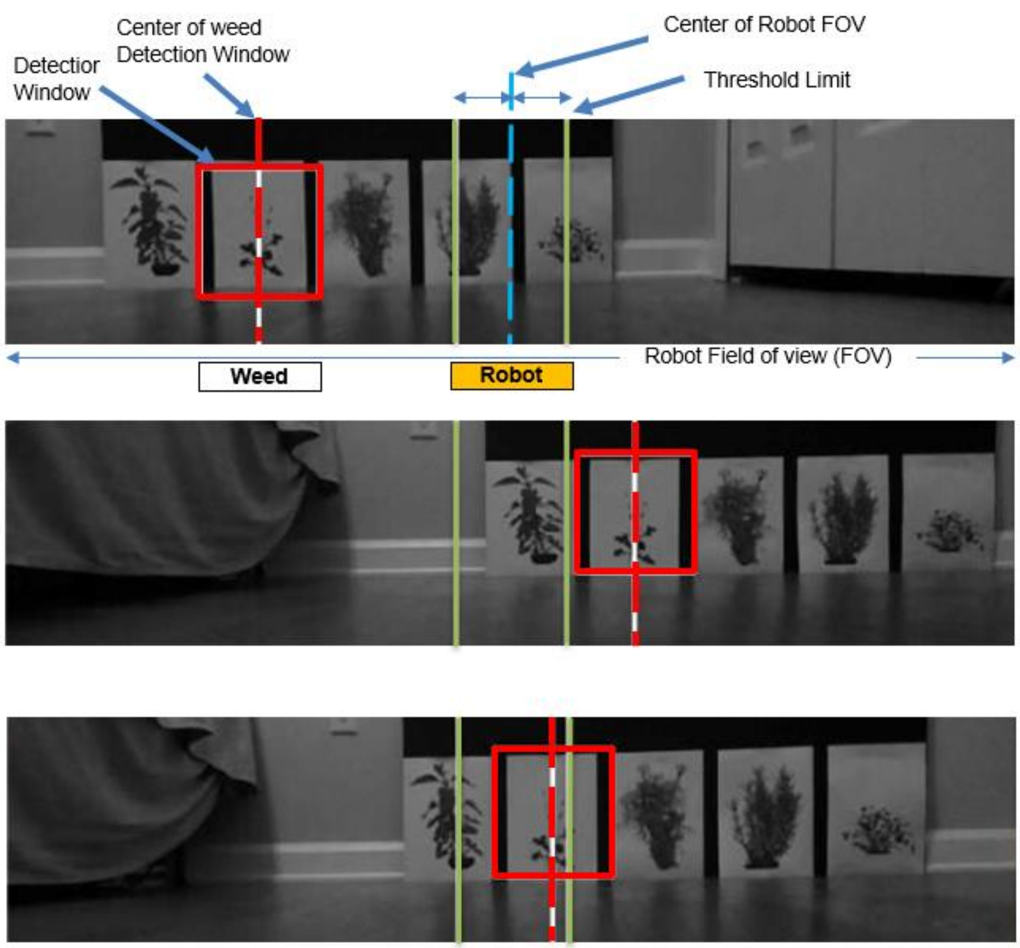
Set 1: Weed is in position 1

Set 2: Weed is in position 2

Set 3: Weed is in position 3

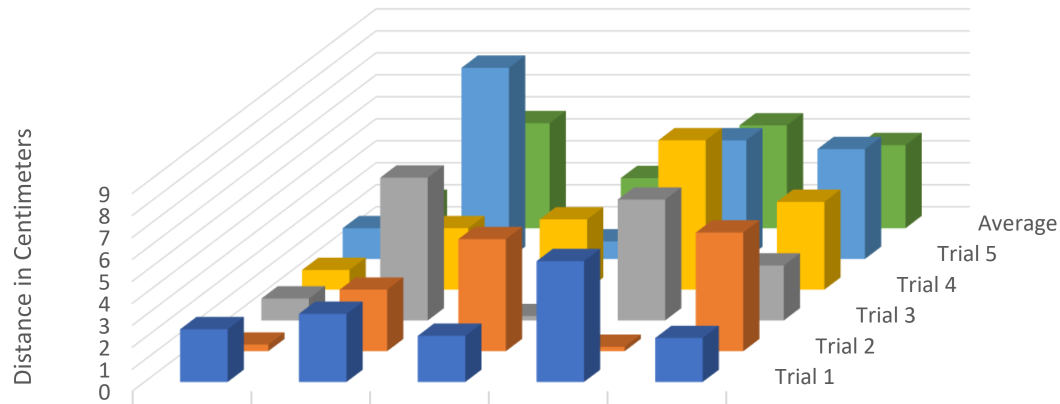
Set 4: Weed is in position 4

Set 5: Weed is in position 5



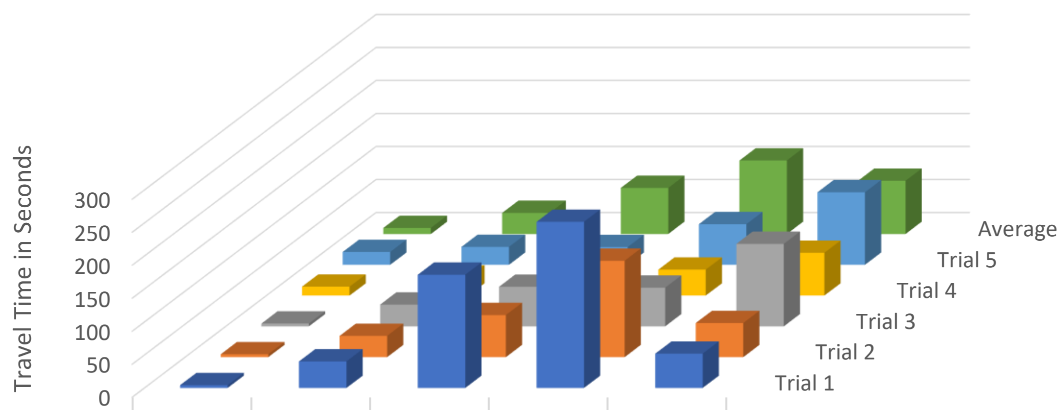
Results

Distance from the axis of the Robot to Weed, with the Weed in Position 1



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	2.4	3.1	2.1	5.5	2
Trial 2	0.3	2.8	5.1	0.2	5.4
Trial 3	1	6.5	0.2	5.5	2.5
Trial 4	0.9	2.8	3.2	6.8	4
Trial 5	1.4	8.7	0.8	5.4	5
Average	1.2	4.78	2.28	4.68	3.78

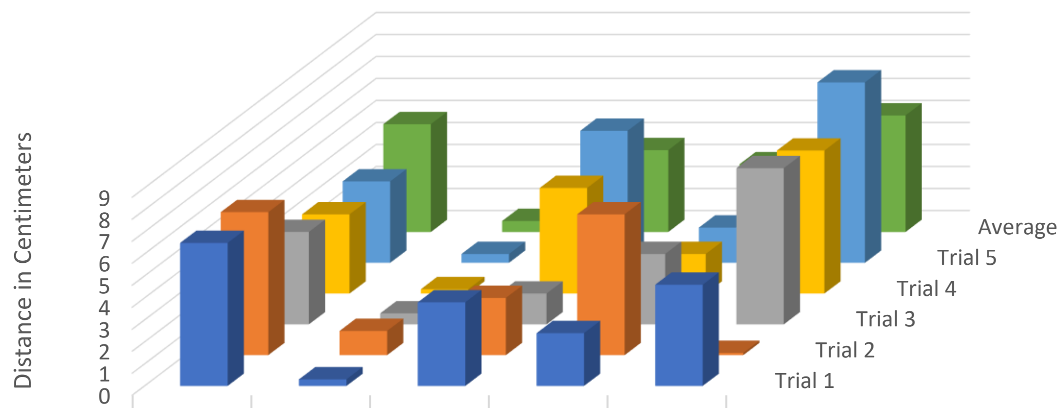
Total Detection and Travel Time, with the Weed in Position 1



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	4.2	40.2	171.5	251.7	51.9
Trial 2	4.4	32.2	63.8	146	51.7
Trial 3	4.3	33	60	58.6	125
Trial 4	13.5	27.3	27	39.3	64.8
Trial 5	19.4	27.1	26.9	61.5	109.9
Average	9.16	31.96	69.84	111.42	80.66

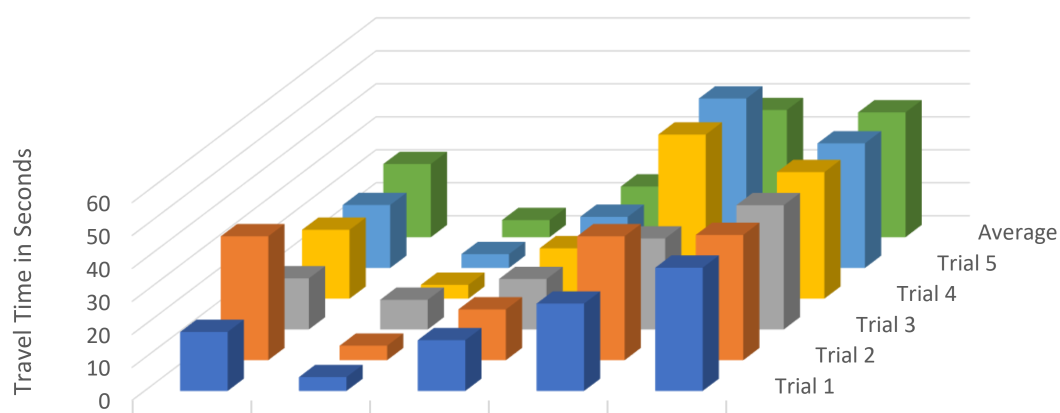
In this set of trials, the weed was placed in position 1. The average distance to the center of the weed was 3.34 centimeters. The greatest distance was 6.8 cm, and the least distance was 0.2 cm. The average detection and travel time was 60.61 seconds. The greatest time was 251.7 s and the least amount of time was 4.2 s.

Distance from the axis of the Robot to Weed, with the Weed in Position 2



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	6.5	0.3	3.8	2.4	4.6
Trial 2	6.5	1.1	2.6	6.4	0.1
Trial 3	4.2	0.5	1.4	3.2	7.1
Trial 4	3.6	0.2	4.8	1.8	6.5
Trial 5	3.7	0.4	6	1.6	8.2
Average	4.9	0.5	3.72	3.08	5.3

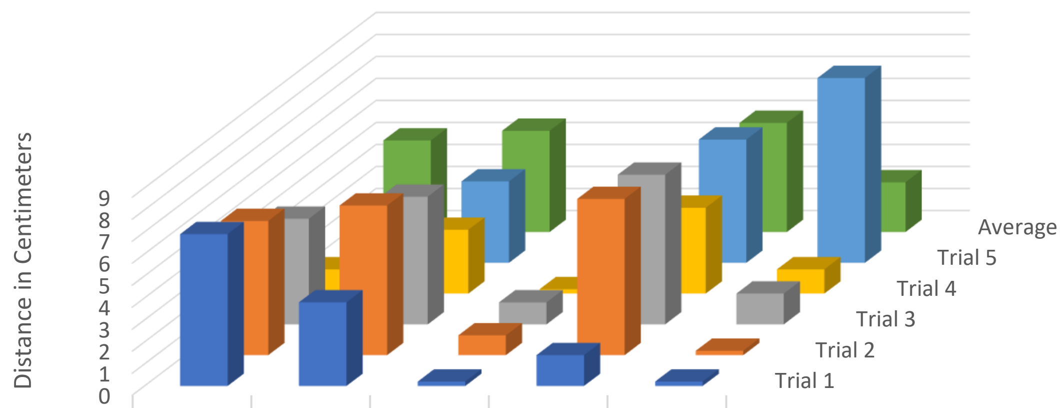
Total Detection and Travel Time, with the Weed in Position 2



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	17.9	4.2	15.4	26.5	37.4
Trial 2	37.6	4.4	15.4	37.6	38
Trial 3	15.5	9	15.3	27.6	37.7
Trial 4	20.9	4.2	15.3	49.8	38.4
Trial 5	19.1	4.2	15.5	51.4	37.8
Average	22.2	5.2	15.38	38.58	37.86

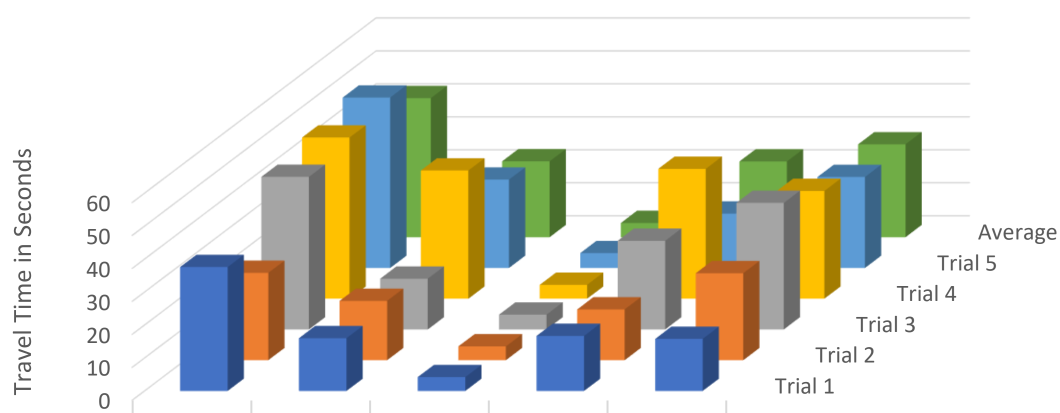
In this set of trials, the weed was placed in position 2. The average distance to the center of the weed was 3.5 centimeters. The greatest distance was 8.2 cm, and the least distance was 0.1 cm. The average detection and travel time was 23.84 seconds. The greatest time was 51.4 s and the least amount of time was 4.2 s.

Distance from the axis of the Robot to Weed, with the Weed in Position 3



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	6.9	3.8	0.2	1.4	0.2
Trial 2	6.1	6.8	0.9	7.1	0.2
Trial 3	4.8	5.8	1	6.8	1.4
Trial 4	1.1	2.9	0.2	3.9	1.1
Trial 5	1.9	3.7	0.4	5.6	8.4
Average	4.16	4.6	0.54	4.96	2.26

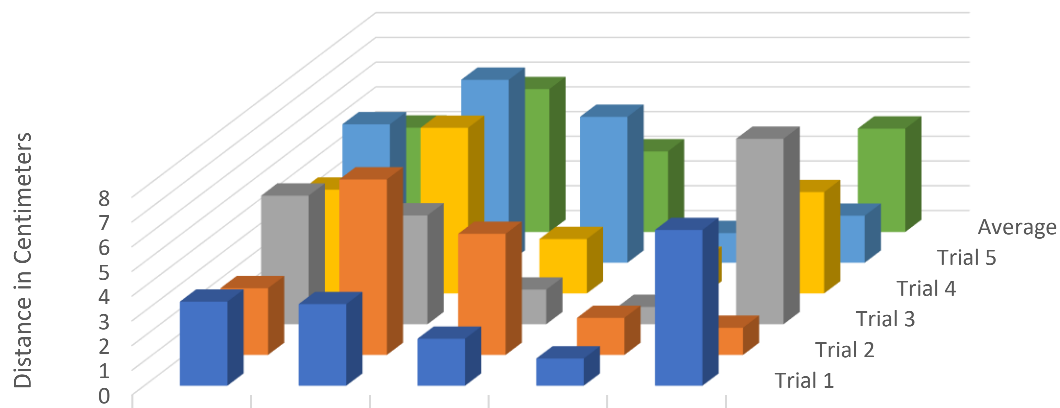
Total Detection and Travel Time, with the Weed in Position 3



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	37.6	16	4.2	16.7	15.8
Trial 2	26.5	18	4.2	15.4	26.4
Trial 3	46.3	15.4	4.5	26.9	38.4
Trial 4	48.9	38.9	4.2	39.4	32.7
Trial 5	51.7	26.8	4.5	16.5	27.6
Average	42.2	23.02	4.32	22.98	28.18

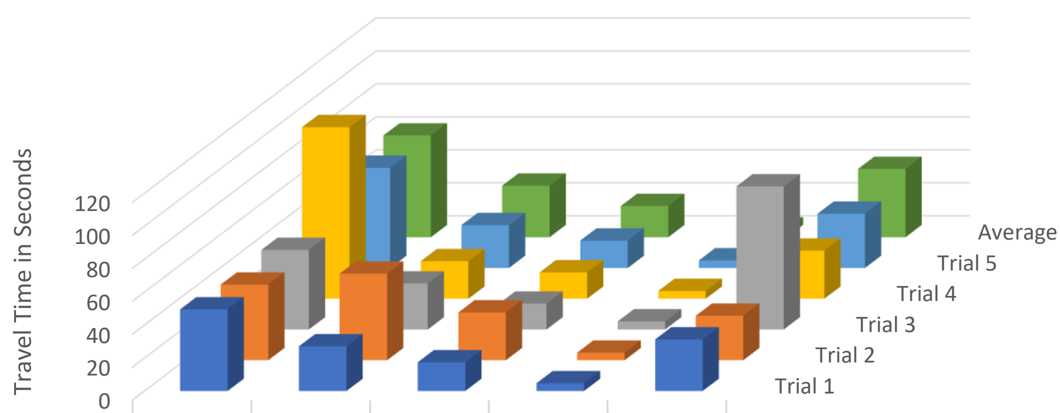
In this set of trials, the weed was placed in position 3. The average distance to the center of the weed was 3.30 centimeters. The greatest distance was 8.4 cm, and the least distance was 0.2 cm. The average detection and travel time was 24.14 seconds. The greatest time was 51.7 s and the least amount of time was 4.2 s.

Distance from the axis of the Robot to Weed, with the Weed in Position 4



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	3.4	3.3	1.9	1.1	6.3
Trial 2	2.7	7.1	4.9	1.5	1.1
Trial 3	5.2	4.4	1.4	0.7	7.5
Trial 4	4.2	6.7	2.2	1.4	4.1
Trial 5	5.6	7.4	5.9	1.2	1.9
Average	4.22	5.78	3.26	1.18	4.18

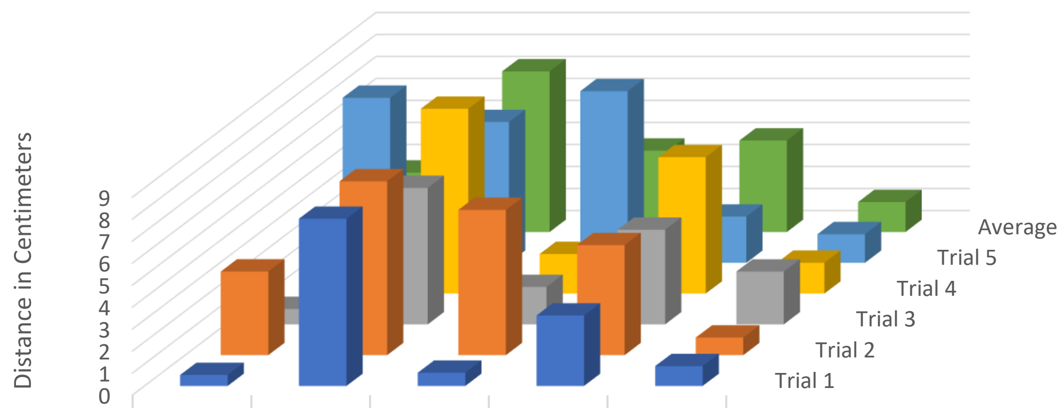
Total Detection and Travel Time, with the Weed in Position 4



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	49.5	27.1	17.4	4.7	31.3
Trial 2	45.9	52.5	29	4.6	27
Trial 3	48.3	27.9	15.7	4.9	86.8
Trial 4	104.1	22.8	16	4.7	29.2
Trial 5	60.8	26	16.6	4.6	32.9
Average	61.72	31.26	18.94	4.7	41.44

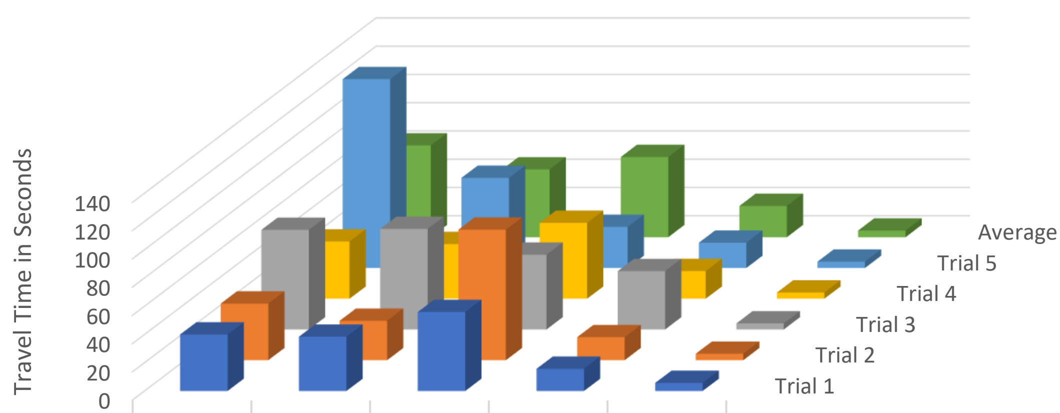
In this set of trials, the weed was placed in position 4. The average distance to the center of the weed was 3.72 centimeters. The greatest distance was 7.5 cm, and the least distance was 0.7 cm. The average detection and travel time was 31.61 seconds. The greatest time was 104.1 s and the least amount of time was 4.7 s.

Distance from the axis of the Robot to Weed, with the Weed in Position 5



	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	0.5	7.6	0.6	3.2	0.9
Trial 2	3.8	7.9	6.6	5	0.8
Trial 3	0.7	6.2	1.7	4.3	2.4
Trial 4	1	8.4	1.8	6.2	1.4
Trial 5	7.5	6.4	7.8	2.1	1.3
Average	2.7	7.3	3.7	4.16	1.36

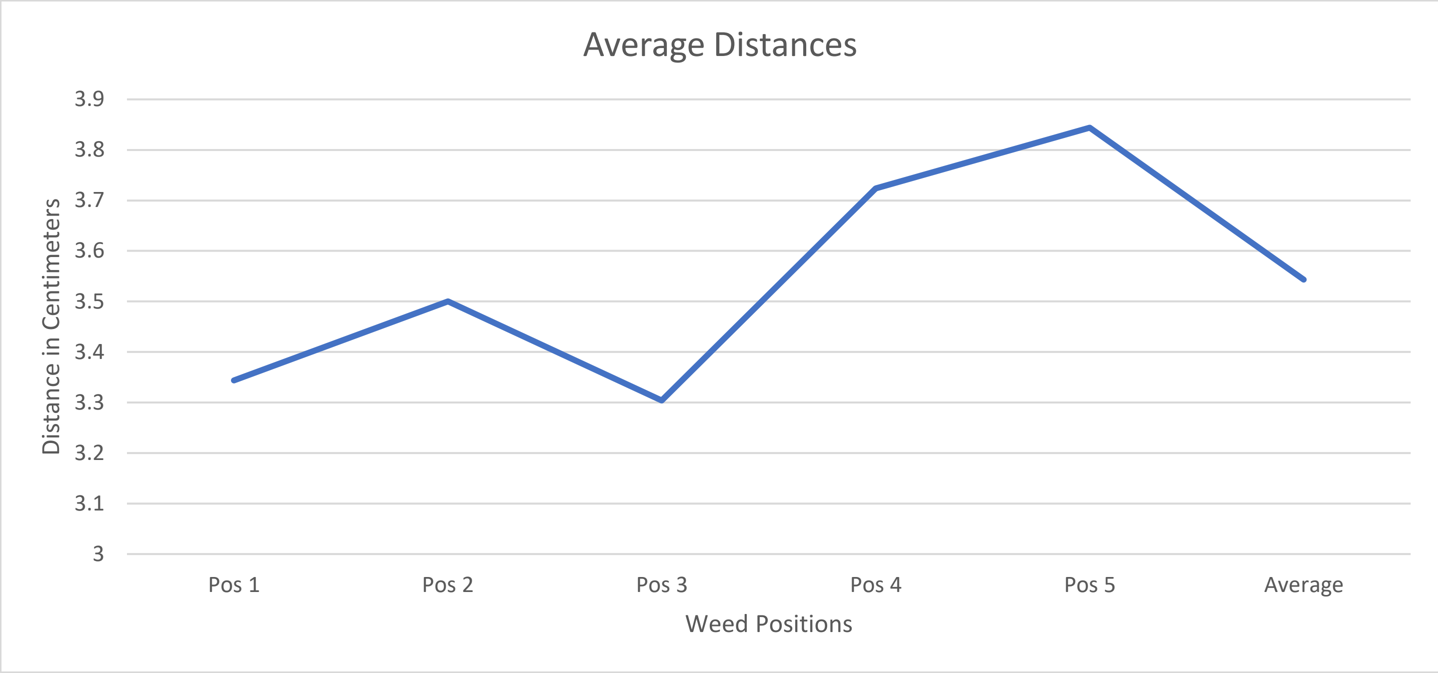
Total Detection and Travel Time, with the Weed in Position 5

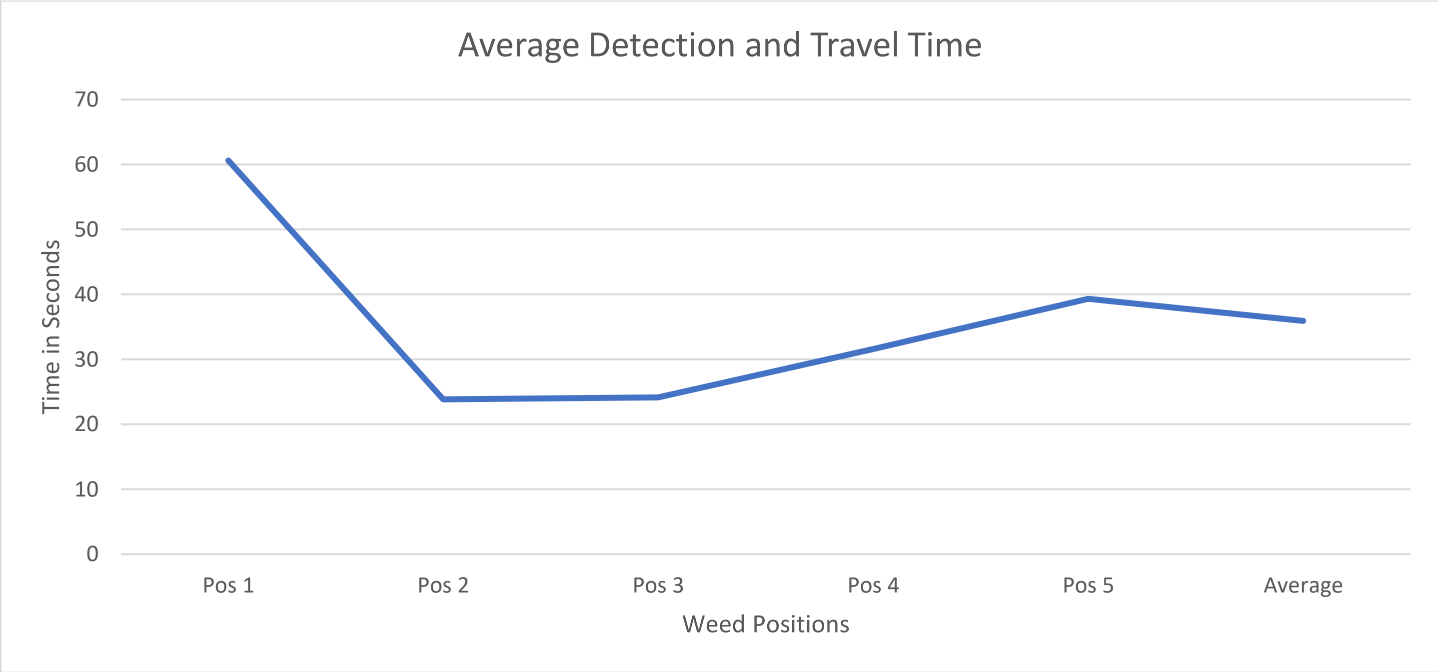


	Position 1	Position 2	Position 3	Position 4	Position 5
Trial 1	40	38.4	55.9	15.7	5.7
Trial 2	40.1	27.9	92.4	16.3	4.6
Trial 3	70.5	71.2	52.9	41.3	4.3
Trial 4	40.5	38.7	53.7	19.6	4.4
Trial 5	133.7	63.8	29.1	17.9	4.5
Average	64.96	48	56.8	22.16	4.7

In this set of trials, the weed was placed in position 5. The average distance to the center of the weed was 3.84 centimeters. The greatest distance was 8.4 cm, and the least distance was 0.6 cm. The average detection and travel time was 39.32 seconds. The greatest time was 133.7 s and the least amount of time was 4.3 s.

Analysis





The graphs show the average time and distance among all five image sets. The average distance between the robot and the weed center was 3.54 cm away. The average time was 35.9 seconds. As you can see, the distances varied throughout the image sets from 3.304 cm to 3.844 cm. Furthermore, most of the average times were around 30 seconds, with one outlier measuring 60.608 seconds.

Conclusion

The goal of this project was to develop and test a robotic vehicle utilizing a Machine Learning based program to detect weeds with at least an 80% accuracy rate. The engineering goal was met as seen by my data collected during the experiment. During the testing, the robot successfully detected the weed 100% of the time. In addition, the robot, after travelling to a detected weed, was 3.54 centimeters away from the center of the weed on average. The iterative process helped to guide the robot accurately with an average detection and travel time of 35.9 seconds. Overall, the robotic vehicle successfully completed its task autonomously.

Application

The program can be improved to detect 3-dimensional plants with backgrounds. In addition, building a robot with a stronger chassis will make it easier to travel over rough terrain outdoors. Weeds can be extracted by adding a gripper attachment to this robot.

Future applications can include programming the robot to extract edible weeds such as dandelion, whose leaves are used in salads. By developing additional attachments, the robot can be used to detect harmful pests and plant diseases, as well as spraying organic pesticides and fungicides to treat the plants. The robot can also provide customized amounts of water and nutrients to plants based on moisture content and nutrient levels in the soil. This can reduce unnecessary water and fertilizer consumption.

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