AMAR – Autonomous Modular Agricultural Robot

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AMAR – Autonomous Modular Agricultural Robot

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Abstract

Weed removal is a task that can benefit from farm automation. However, most automation products are too expensive and are designed for large farms. To address this problem of weed removal for small organic farms and aging farmers, this paper presents the design of the Autonomous Modular Agricultural Robot (AMAR), which is a prototype of a solar-powered farming robot that uses machine learning (ML) algorithms to identify and remove weeds. Initial experiments show that AMAR performs binary classification to decide whether to destroy undesired plants (weeds) or preserve desired plants (crops of peppers). When a weed is detected, a robotic arm cuts the leaves of the weed. AMAR also has the ability to inspect crops without the need for fences or boundary devices, communicates with a user interface that can do several things: track the robot’s location, stop it in an emergency, show weather information, and collect data for improvements to the system.

Introduction

One of the most tedious tasks involved with gardening and farming is weed control. Even small gardens can require hours of weed pulling just for the weeds to grow back in a day or two. Weeds compete with crops and gardens for nutrients from the soil while blocking seedlings’ access to sunlight. Existing solutions to weed removal are herbicides that cause pollution, tractors that are not precise, or workers that are expensive or not available. To address this problem of weed management, this paper shows the development of an automated robot that identifies and cuts weeds by using a camera and robotic arm. The Autonomous Modular Agricultural Robot (AMAR) robot aims to reduce labor costs and eliminate the repetitive manual labor involved in weed pulling.

Autonomous weeding robots have been developed to help organic farmers, such as the weeding robot prototype developed by T. Bakker et al. It autonomously removed weeds and navigated along the rows of crops without crossing field boundaries. The target was sugar beet crops in the Netherlands. Many of the features in their robot, such as the cellular communications that allows the robot to send information to the internet, inspired the design of AMAR. An innovation that AMAR introduces is that it includes machine learning (ML) algorithms to detect weeds.

Hardware Design

When AMAR is deployed in a farm, it autonomously drives through the rows of crops scanning for plants at set intervals and distinguishing between crops and weeds. The camera is connected to a
Raspberry Pi module which runs visual ML algorithms to decide if it is a crop plant or a weed. Once it is registered as a weed, the arm of the robot has a spinning wire that cuts the weed. Then, the robot continues to drive through the rows, scanning for more weeds and repeating this process when weeds are identified. Additionally, the solar panel is used for supplemental charging allowing the robot to run for a longer duration, and to complete its mapped route. The robot communicates via cellular link with a server over the internet. The server is used for verifying the robot’s functionality, in terms of battery life, location, and weather forecast data.

As a result, we designed AMAR according to the functional block diagram (FBD) in Figure 1. At the center, there is the main computational unit, a Raspberry Pi module. It controls the navigation, runs the ML algorithms, acquires sensor data, and controls the weed removal arm. The top and left side of Figure 1, shows AMAR’s sensors including:

- **MPU6050 accelerometer**: to allow the robot to collect precise movement data for collision avoidance and mapping.
- **HC-SR04 ultrasonic sensor**: to identify how far an object is from the robot.
- **NEO-6M-0-001 GPS transceiver**: this location data is sent to the graphical user interface (GUI).

Power is supplied to AMAR through the 12V, 10Ah, LiFePo4 battery. The 10W solar panel charges the battery during the operational mode, and the 12V, 5A, AC-DC transformer charges the battery during the non-operational mode. The battery supplies the charge controller with power, which distributes DC power throughout AMAR’s subsystems.

**Software Design**

There are several types of programs that AMAR runs, depending on which mode of operation: setup mode or operational mode.
Setup Mode

During setup mode, autonomous procedures for AMAR include loading the initial map with a simulated robot in the space at the x and y coordinates of (0, 0). Bootup procedures will be run to include all necessary libraries to run the Operational Mode file. The visual ML algorithm training is also done at this mode. Thus, the Setup Mode should only need to be run once per plant propagation area unless long-duration operations are to be used where library updates may need to be applied.

Our mapping system utilizes an integer NumPy array to allow for autonomous activity with memory of the location of objects, and AMAR, within the plant propagation area without the need for dynamic memory (robot can be shut down and restarted in the same spot without issue). Integers are used to represent different types of objects within the plant propagation area. An example of the generated Robot Map is shown in Figure 2 with the weeded areas updated with a new color.

![Figure 2 - Robot map example](image)

The visual ML model utilizes Tensorflow with a Keras backend. Keras is used for dataset manipulation, preprocessing, and Convolutional Neural Network (CNN) construction. The CNN is a 2-Dimensional, four-layer, network with a 20% layer dropout. The model is compiled using the Adam optimizer to minimize validation losses through sparse categorical cross-entropy utilizing the class parameters. The Nadam optimizer was noisy but trained faster (preferable loss gradient). The model metrics utilized for training the class Tensors are accuracy and mean-squared error (mse). This model is then converted into a .tflite file package for use with Tensorflow-Lite (TF-Lite) on the Raspberry Pi. TF-Lite allows for speedy identification (relative to the use of Tensorflow on the Raspberry Pi) of plants.

Operational Mode

The Operational Mode is the active portion of AMARs autonomous operation. AMAR enters Operational Mode when a command is declared to start weeding. A command is the “\start” command sent by the user. If any interrupts are activated, the program clears the interrupts then continues operations. The pathfinding routes to the closest weeds in front of the robot outside of the previously weeded area. When no weeds are in front of AMAR, the pathfinding utilizes a modified A* algorithm to find the closest weed without driving over crop rows. Sensory input provides movement data for calculation into movement information for reference against the map to adjust
AMAR onto the correct path. When AMAR reaches the new location, it tests again if there is a crop in the vicinity, and weeds the local area using a sweeping motion if a weed is detected.

**Implementation and initial tests**

AMAR was tested in early December of 2021. The robot was tested indoors using a few pepper plants as crops, as show in Figure 3. As for the accuracy of the ML algorithm, it was low (around 6%) and our tests with real crops were very limited, due to the winter months. We trained the model with static images. Then, in the operational mode, the Tensorflow-Lite interfaced with Raspberry Pi to gather streaming/static image data through the video camera referenced from the trained Tensorflow model Tensor heatmaps to verify plant type.

![Figure 3 - Initial test of AMAR using peppers](image)

If a USB device is affixed with the correct folder name, then the ML software stores identified plants with their percentage confidence level and class name in the image. The images within the directory are shown in Figure 4 and the numbers attached to the images are the confidence level of the ML algorithm that the seen plant was a pepper plant (such as 7.056% for the top left figure).

![Figure 4 - Images of identified plants by the ML model](image)
Summary and Conclusions
AMAR is a four-wheeled, tracked, robot built from T-slot aluminum tubing, 3D-printed materials, and connective components. This robotic system consists of several subsystems. It was completely developed by the students and it was a challenging project. Additional tests are needed to verify the ML algorithms’ performance. Also, we have identified several areas for improvement. First, switching back to Tensorflow (from TF-Lite) should fix most errors in plant identification even though it will take around 250 msec. Second, we plan to research other mapping tools to be used in the setup mode. Finally, we should offload the computational unit (Raspberry Pi) to mainly run the ML algorithms, and use an external microcontroller for sensor data acquisition and pre-processing. In this way the Raspberry Pi can perform complex tasks more effectively.

References

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Tim graduated with a major in Electronic Systems Engineering Technology (ESET) from Texas A&M University in December 2021. Tim proposed the idea for this project and worked on the ML algorithms.

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