

Weed Detection and Spot Spraying Robot for Precision Agriculture

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Abstract - Agriculture is the main source of way to satisfy the need of food for human beings. Nowadays, with the help of day- to-day growing technologies, robotics is used in the agriculture field to save time and reduce the wastage of the harvest. Through the application of Artificial Intelligence and computer vision, the automation of agricultural field tasks becomes achievable. In agriculture, robots are mainly used for harvesting, fertilizing, and irrigation. We identified that there is a gap in the weed detection and herbicide spraying system while navigating through the crop rows autonomously. Based on our research, we propose the development of an autonomous robot with the capability to automatically detect weeds and apply herbicides. As a result of this research, the fertilizers and nutrients that are consumed by the weeds can be saved and then crops will be able to consume the nutrition properly.

Keywords: AI, Computer Vision, Robotics, Image processing, YOLOv8.

I. INTRODUCTION

Agriculture, a crucial key to human sustenance and a fundamental need for economic advancement in societies, plays a pivotal role in addressing the escalating need for sustenance and agricultural necessities. Nonetheless, farmers confront a multitude of intricate hurdles, especially in the domain of weed management, while endeavoring to secure the enduring viability of the agricultural sector. Effective weed management is pivotal to farmers' success, as unchecked weed growth can significantly impede crop growth and diminish agricultural productivity. The judicious use of herbicides can mitigate weed-related challenges and enhance crop yields, offering farmers a valuable tool for sustainable agricultural practices but usage of herbicides could lead to health risks. The research begins by providing statistical insights into the current use of robotics in agriculture. A study conducted based on a significant portion of labor tasks, namely 71%, is currently performed by human workers, with the remaining 29% delegated to automated robots. Such data underscores the untapped potential for heightened implementation of robotics within the agricultural sector in the forthcoming

years. Moreover, findings from the World Robotics Report shed light on the prevalence of industrial robot density in developed countries that exhibit limited adoption due to the prohibitively high costs associated with robotic technologies. However, the rapid advancements in AI techniques hold the promise of surmounting these cost barriers, thereby paving the way for a broader market share of agricultural robots by 2030. The objective of this research is to create a fully autonomous system that combines computer vision, active navigation, and image processing for the advancement of precision agriculture. A critical component of this system is the perception system, which plays a pivotal role in understanding the environment and accurately identifying crop rows. The robot is equipped with the ability to identify weeds during navigation and selectively target herbicides when needed. By surmounting the limitations inherent in traditional weed control methods and harnessing advanced technologies, this research project seeks to furnish a sustainable and efficient solution for precision agriculture. The proposed robot could cut off the manual labor requirements and enhance crop yield optimization by reducing herbicide application. By doing so, it aims to ensure the sustained sustainability of the agricultural sector while also mitigating detrimental environmental effects. The subsequent sections of this paper will delve into the technical aspects of the proposed solution, encompassing the underlying technologies, algorithms, and data requirements. Expertise in weed biology, crop science, agricultural engineering, robotics, and sensors will be essential, alongside comprehensive data collection to facilitate the training and evaluation of the autonomous system.

II. RELATED WORK

Weeds are unwanted plants that compete with crops for nutrients, water, and sunlight, and can significantly reduce harvest. Manual weeding is a time-consuming and labor-intensive process that requires a significant number of resources and can be costly for farmers. As a solution, farmers are spraying herbicides on the weeds. Herbicides are chemicals that are sprayed on weeds to kill or control their growth. This has made herbicides a popular and cost-effective solution for weed control in agriculture. However, the use of herbicides can also have negative impacts on the environment,

including soil and water pollution, and can pose health risks to humans and animals [1]. Herbicides can be applied by targeting only the weeds and leaving the crops unharmed but as humans, accurate targeting is beyond our capabilities, and it will be a tedious process. As a solution with the help of robotics and Artificial Intelligence (AI) technologies [2], our system can provide a precise and targeted herbicide application that reduces the amount of chemicals needed and minimizes exposure to humans and the environment. To have a good understanding, it needs proper sensory information. But nowadays, those sensors are selling at a high cost. Due to that reason, the budget of making a robot is pretty much expensive and that cannot be afforded by a farmer. Since AI techniques are exponentially growing, researchers will be able to precept the environment without using expensive equipment. In this research component, our system is capable of working as a fully autonomous system by using computer vision and image processing with an active navigation system. To navigate the system, the robot needs to understand the environment using the perception system first. By using the imaged processed data, it needs to identify the crop row. After determining the path, the robot itself will navigate through the selected crop row. While navigating through the path, it detects the weeds. If the weed is detected, robots need to spray the herbicides accordingly. In the paper [3], You Only Look Once (YOLO) version 3 is employed for weed detection in an agricultural field. The authors successfully developed a highly accurate model for detecting weeds. In our research, the weed detection system was developed using the YOLOv8 nano model, which employs 3.2 million parameters, a considerably lower number compared to the systems proposed in [4] and [5]. In recent years, due to the growth of AI and high-end technologies, it has created many opportunities for researchers. This section delves into the utilization of autonomous systems for agricultural applications by various researchers.

The perception of a computer vision rover is essential for its success in various applications. Different methods sensors and algorithms are identified regarding the perception of a rover. Sensors like cameras, Light Detection and Ranging (LiDar), Radar, and methods like optical flow, object detection, Stereo vision, Optical flow, and Convolutional Neural Networks are examples. In perception, autonomous navigation is the most important component of a computer vision rover. Talha Tariq published a research paper [6] about the design and implementation of an autonomous rover using computer vision algorithm. Rausch et al did research about autonomous navigation for visual odometry in conjunction. Junjie Luo et al proposed a paper called Semantic Riverscapes: Perception and Evaluation of linear landscapes from Oblique Imagery using computer vision [7]. The sensing capabilities of a computer vision rover are not complete

without the ability to track objects. Richard Szeliski published a book related to computer vision Algorithms and Applications [8]. Yang et al. (2019) came up with a method for tracking objects that made use of a particle filter and was successful in achieving a high degree of accuracy. Authors Long et al. published an article titled “Fully Convolutional Networks for Semantic Segmentation.” In this study, a fully convolutional neural network, or FCN, was presented for semantic segmentation. Novel Edge Detection Algorithm for Mobile Robot Path Planning research done using computer vision technology in 2018 by Rami Al-Jarrah et al. In typical agriculture, people manually spray herbicides on the weeds, and it causes unhealthy production in the end also it will make biological effects of these chemicals will lead to genetic damage to the consumers[4].



Figure 1: Design of the SPARROW

There are various kinds of approaches have been proposed to address the problem. Those are included with techniques like computer vision, machine learning and deep learning. Several types of navigation systems were introduced by the researchers. One of them is a LiDar-based navigation system. Authors of [9], [10] are using LiDar-based system that used a laser to detect the surroundings and capable of creating a 3D map based on the sensed information more accurately. Global Positioning System (GPS) based navigation system [11]–[13] is another autonomous navigating system that uses satellite signals to determine the location of a vehicle and provide directions to a desired destination. The primary limitation of systems such as LiDar-based and GPS-based navigation is their cost- effectiveness. Our research is focused on vision-based navigation, which is a cost-effective mechanism for autonomous navigation [14]. Vision-based navigation has high flexibility because it can be used in a wide range of applications. Also, it provides real-time processing which allows robots to make navigation decisions more quickly.

III. METHODOLOGY

The system encompasses four primary subsystems that operate to deliver effective weed detection and targeted herbicide spraying, as outlined below.

Figure 1 illustrates the design of our robot. The complete system is interconnected through the utilization of the Robotic Operating System (ROS) middleware. Our architecture is linked via ROS nodes and topics and it encompasses four fundamental subsystems.

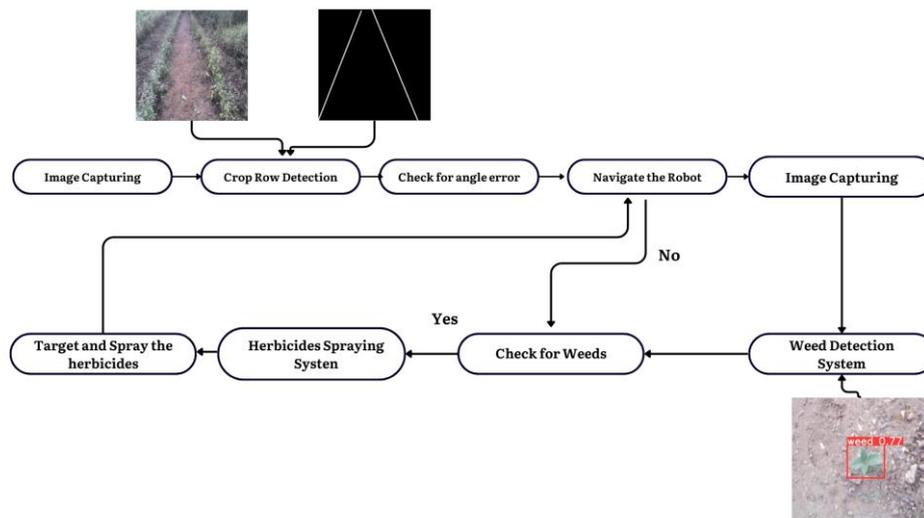


Figure 2: System diagram of the SPARROW

An OpenCV code snippet is used to record the environment. After collecting the dataset, that dataset is resized and then converted into HSV format. After adding the proper thresholding mechanism [15], [16], the system was able to accurately identify the crop rows. Triangle scanning algorithm was used to identify the middle of the crop rows. Then the angle error was calculated using it. This angle error was published to the subscriber node which is the next phase in our system.

B) Vision-based autonomous navigation system

The robot’s autonomous navigation is controlled by the vision-based autonomous navigation system. Apart from other navigation methods, vision-based navigation has several benefits including robustness and low cost. This system is integrated with other subsystems. After detecting a weed-by-weed detection system, navigation needs to stop and after spraying the herbicides by the sprayer system, navigation needs to be continued. As well as perception system and navigation system are bound with each other and with the help of these two systems only our proposed system will be able to achieve the vision based navigation through the crop row. Because of that, the dataset needs to be collected as an initial

A) Vision-Based Perception System

The process of identifying the crop row is the main goal of the vision-based perception system. To attain this goal, a vision-based approach has been adopted, involving the capture of environmental data through the use of a webcam. The webcam is positioned at the front of the robot to capture data from the crop rows. Image processing is implemented in the Raspberry Pi 4 model. To collect the dataset, a video was captured that can be later sliced into image frames.

step in this entire system. To have high accuracy in the navigation, the dataset should be collected from the point of view of the robot. Due to this reason, the navigation was done using Bluetooth commands [17]. Bluetooth navigation is achieved by attaching the HC-06 Bluetooth module to the Arduino Uno and the robot is controlled by using the mobile application known as the “Bluetooth RC controller”. Vision-based navigation system implemented as a three-step process. The initial step is to gather the position values from the perception system. The second step is to calculate the velocities with respect to the position values. A type of geometry message called “twist” library is used to store the velocities. Twist describes the movement in empty space by separating it into its components of straight-line motion and rotational motion. The final step is calculating the motor-controlling values for the relevant velocity values. After calculating the velocities, the system needs to control the DC motors which are connected through the Arduino. To do that, the communication between the ros and Arduino is done by using the rosserial package. The communication between these steps is done by using the concept of publisher and subscriber nodes.

C) Weed detection system

The weed detection system [18], [19] was created using, You Only Look Once (YOLO) version 8. YOLOv8 uses a new model backbone called CSPDarknet53, which utilizes a more efficient backbone than the Darknet53, as seen in other versions, this enhances the model’s effectiveness in detecting objects of various sizes and scales. Also, YOLOv8 is faster and more accurate than the other versions. Figure 3 shows the performance of YOLOv8.

The method of creating the dataset is the same as the perceived data. A separate camera was installed in the front of the robot to detect the weeds. Other than that, the weed detection model is implemented in the Raspberry Pi 4 model.

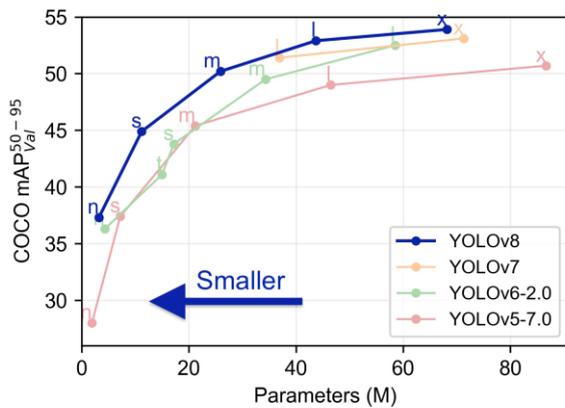


Figure 3: Performance of YOLOv8

After recording videos by using a webcam, those videos are sliced into image frames using an OpenCV code snippet. The dataset consists of weeds that are growing in the Sri Lankan field. The dataset includes 700 images and their respective labels. Roboflow web application was used for data annotation. During data collection, emphasis was placed on ensuring that the collected data aids the model in distinguishing between weeds and crops. YOLOv8 nano model was used to train the model. This model utilizes a minimal number of parameters, making it suitable for running on lower processing power. When weeds are detected, a 'stop' signal is transmitted to the navigation system and halted navigation. The x and y coordinates of the bounding box are employed to determine the center coordinates of the weed. This center point value is subsequently published to the sprayer system using ROS communication.

D) Herbicides Sprayer System

Our robot’s primary goal is realized by precisely targeting and applying herbicides to identified weeds, a pivotal and intricate task within the agricultural domain. Figure 4 shows the herbicide sprayer system of our robot.

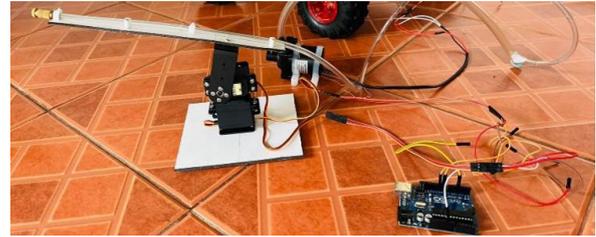


Figure 4: Design of the herbicides sprayer

The design of the sprayer system is a turret, and it is implemented using two MG996 metal wheel servo motors. These two servo motors are used for tilting and panning. After gathering the weed position from the weed detection system, the sprayer system will be notified using a ROS node. The spraying target is important for effective spraying. So, the target of the sprayer will be the center of the detected bounding box. So, the turret could rotate to the relevant position. The relevant angle values are published to the Arduino using a serial communication which is implemented using rosserial package. Besides that, If there are multiple weeds are detected, the sprayer is capable of spraying all the detected weeds. At the same time after the completion of spraying, the system needs to notify the navigation system to continue the navigation.

IV. RESULTS AND DISCUSSION

Our proposed system provides a systematic solution for one of the tedious tasks faced by the farmers which is manual weeding. Our solution is a combination of technologies such as computer vision, robotics, and autonomous. Each system functioned collaboratively and efficiently with each other to produce real-time and accurate results. Since most of the farming is done in a crop-wise manner, there has already been implemented groundwork which helps the robot to understand the environment. So, the robot was able to recognize the crop row by utilizing the image processing technique which was developed by using triangle scanning [20]. The following figure represents the result of our image processing using our implemented algorithm that highlights the crop row in the captured image. This will result in identifying the navigation pathway of the robot.



Figure 5: Process of crop row detection. a: Input image, b: ExG Image

As shown in Figure 5, the proposed system identified the crop row from the image and it requires only small amounts of processing power. The major benefit of such a system is that can be used in any kind of agricultural field that plants the crops in row-wise with some minor modifications at a low cost. In the next stage, the system calculates an error, which corresponds to the steering angle required for the robot in relation to the center of the path. To achieve autonomy in a robot, it is crucial to determine this path-related error. Subsequently, this calculated error is utilized to precisely determine the required motor control velocities. There are primarily two types of velocities involved: linear velocity and angular velocity, each encompassing three dimensions denoted as x, y, and z. These values are stored and managed using the Twist library to handle three-dimensional Cartesian coordinates. As our robot is a mobile platform, the linear y and z, as well as the angular x and y, are consistently set to zero. For forward and backward motion, the linear x value is assigned a positive value for moving forward and a negative value for moving in reverse. Similarly, to facilitate turning left or right, positive and negative values are assigned to angular z, respectively. Initially, navigation is implemented using Bluetooth commands and the robot is controlled using “Bluetooth RC controller”, the result was very accurate when it was controlled using Bluetooth commands. Even though this is a manual method, this was helped to test the functionality of the robot and its relevant components such as motor drivers, and to collect the dataset. Besides that, the weed detection system examined weeds in real time while moving through the crop row. The presence of weeds is detected using the CNN-based YOLO algorithm.



Figure 6: Outcome of the weed detection model

Figure 6 illustrates the results of the weed detection model, demonstrating how it predicts the presence of weeds. Real-time webcam input is fed to the model, enabling it to rapidly detect weeds. The model can effectively identify weeds while the robot is in motion. The herbicide sprayer is designed like a turret. When the power is provided by the relay module, the stored herbicide in the container is pumped and our sprayer system is able to spray a distance of 50 cm. It

is capable of targeting the center of the bounding box and spraying the weeds.

Figure 7 depicts the precision-recall curve that serves as an evaluation method for assessing the weed detection algorithm’s effectiveness. It visualizes precision which is the proportion of correctly predicted positive detections among all predicted positives that is reflected on the y-axis and recall which is the algorithm’s ability to capture actual positive instances that is reflected on the x-axis. The Area Under the Precision-Recall Curve (AUC-PR) is the evaluation metric used to measure the algorithm’s outstanding performance.

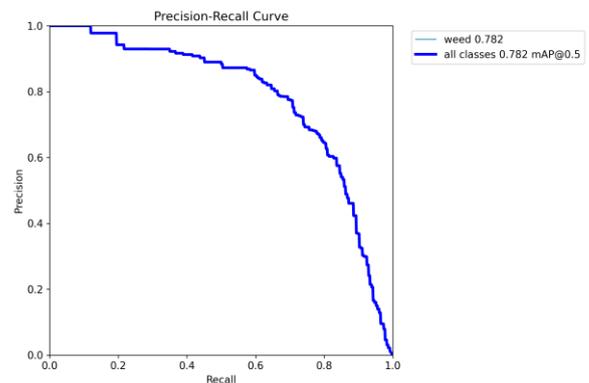


Figure 7: Precision-Recall curve

V. CONCLUSION

Autonomous robot for precision agriculture has the potential to revolutionize the farming industry. This research paper has provided a detailed exploration of the important components and functions of such a robotic system. By integrating advanced technologies like computer vision, machine learning, and robotics, the autonomous robot can accurately detect and identify weeds in real time. This capability allows farmers to significantly reduce the labor-intensive task of manual weed control and minimize the use of herbicides, promoting sustainable and environmentally friendly. The robot’s spot spraying mechanism enables precise and targeted application of herbicides, minimizing chemical usage while effectively suppressing weed growth. This not only reduces overall weed management costs but also contributes to the preservation of soil health and biodiversity. Moreover, the robot’s autonomy enhances operational efficiency by reducing human intervention and improving farming productivity. With the robot optimizing the use of fertilizers, water, and other resources based on weed density and distribution data, farmers can benefit from increased crop yields and improved resource allocation. While this research paper has proposed a weed detection and spot spraying autonomous robot, it is crucial to acknowledge the need for practical implementation and further field testing. Future research should focus on optimizing the robot’s performance

in various agricultural environments and crop types, as well as integrating additional sensors to enhance monitoring and decision-making capabilities. The weed detection and spot spraying autonomous robot represents a significant advancement in precision agriculture. Its potential to revolutionize weed management practices, increase productivity, and promote sustainable farming methods makes it a valuable tool for modern agriculture. With additional improvements and broader acceptance, this technology possesses the potential to revolutionize crop cultivation, leading to a more efficient, environmentally friendly, and economically sustainable agricultural sector.

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