ISSN No:-2456-2165

Integrating Robotics and Computer Vision for Precision Agriculture: An Autonomous System for Weed Control and Plant Health Monitoring

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Abstract:- The creation of a novel robot created especially for agricultural situations is described in this study. While ensuring the security of the primary crop, the robot combines cutting-edge features, such as weed removal and plant health monitoring. The robot can precisely identify and classify various kinds of weeds and plants thanks to its 5DOF robotic arm, servo gripper, and state-of-the-art computer vision algorithms. A camera system also makes it possible to track plant health and find soil moisture. The robot is self-sufficient and runs on a 12V battery with efficient energy use. The suggested method for getting rid of weeds makes use of a robotic arm-mounted nozzle and a servo gripper for precision weed removal. Additionally, the robot can drive independently and avoid obstacles in diverse agricultural settings thanks to route identification employing the ground-breaking idea of pixel summation. Field experiments have shown the robot's effectiveness in lowering weed populations, enhancing plant growth, and collecting useful information on the health of plants and the moisture level of the soil. This robot has the potential to revolutionize the agricultural industry by reducing the demand for human labour and increasing productivity and sustainability in farming. This project benefits farmers, agricultural enterprises, and researchers in the field of agriculture by providing an effective and practical solution for weed eradication, plant health monitoring, and automation in agriculture.

Keywords:- *Computer Vision, 5 Degrees of Freedom, Weed Detection, Weed Classification, Weed Removal, Soil Moisture, Plant Health Monitor (PHM), Path Detection.*

I. INTRODUCTION

A. Background and Motivation

WEED infestation is a major problem in modern agriculture, resulting in lower crop yields, higher expenses, and environmental issues. Traditional weed management techniques frequently include human labour or the application of chemical pesticides, which can be time-consuming, labour-intensive, and perhaps environmentally hazardous. Effective monitoring of plant health is also essential for maximising agricultural output and reducing yield losses. However, the accuracy, real-time data collecting, and automation capabilities of current monitoring approaches may be lacking.

There is a rising need for cutting-edge technology that can effectively manage weed populations while preserving the health and yield of crops to solve these issues. In the realm of agricultural robotics, autonomous robots have become a viable option with the potential to completely change weed control and plant health monitoring.

The goal of this project is to create a special robot that is made especially for agricultural situations. To effectively eradicate weeds and monitor plant health, this robot aspires to incorporate cutting-edge technology, such as computer vision, robotic arm manipulation, and autonomous navigation. Farmers may minimize labour-intensive chores, lower the usage of chemical pesticides, and make wise judgements based on real-time data regarding plant health and soil conditions by automating these procedures.

The main goal of this project is to develop and deploy a flexible agricultural robot that can accurately and independently detect weeds and remove them while concurrently monitoring environmental conditions and plant health. We hope to enhance agricultural practices by reaching these goals, which will encourage production, sustainability, and minimal environmental effects. Fig.1 is the constructed model of robot.

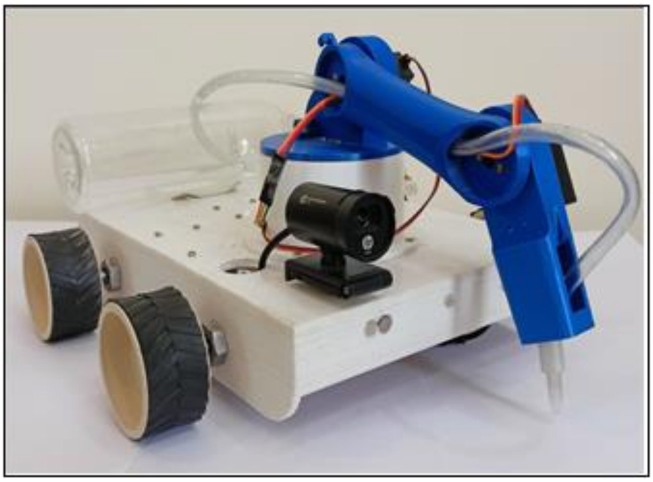

Fig 1 Working Model of Robot

B. Problem Statement

The traditional approaches of weed control and plant health monitoring in agricultural settings have several drawbacks and difficulties. Manual weeding is time-consuming, labour-intensive, and frequently not feasible for large-scale farming operations. Despite its effectiveness, chemical herbicides can harm the environment, people's health, and unintended crops. Additionally, real-time data gathering, automation, and accurate crop status evaluation are frequently lacking in existing plant health monitoring approaches.

These restrictions need the creation of a novel system that can get around them and offer effective, automated, sustainable, and plant health monitoring in agricultural fields. An autonomous robot that can accurately detect and eliminate weeds while also keeping track of plant health indicators including growth, moisture content, and disease indications is required. Farmers may increase agricultural output, cut labour expenses, and make well-informed decisions for prompt interventions with the help of such a robot.

Additionally, the robot should be outfitted with cutting-edge technology including route detection skills to move around the fields while avoiding obstacles, computer vision algorithms to recognise and categorise various weed species effectively, and robotic arm manipulation. Engineering innovation, effective algorithms, and reliable hardware implementation are all needed to integrate these features into a single robotic system.

The goal of this project is to overcome these constraints by creating a special agricultural robot that can monitor plant health and autonomously eradicate weeds. To provide an effective and long-lasting solution for weed control and plant health management in agriculture, the suggested robot attempts to combine cutting-edge technologies such as computer vision, robotic arm manipulation, and route detection.

C. Objective and Research

The main goal of this project is to design, build, and test a unique agricultural robot with capabilities for autonomous weed removal and plant health monitoring. The following are the precise goals:

- Create a reliable robotic system: Create a flexible robot platform with a 5DOF robotic arm, a servo gripper for accurate weed removal, and a spray module for precision herbicide administration. Along with inbuilt sensors for environmental data collecting, the robot should also include a camera system for recording and capturing images.[1]
- Use computer vision algorithms to detect and categorise weeds: Create and improve computer vision algorithms to correctly identify and group different weed species in real time. The robot should be able to distinguish between crops and weeds thanks to the algorithms, making it easier to choose the best eradication methods for each type of weed.
- Enable autonomous path identification and navigation: To allow the robot to independently traverse across agricultural fields, implement a path detection system based on the idea of pixel summation. For efficient weed eradication and plant health monitoring, the system should enable the robot to recognise routes, avoid barriers, and provide efficient field coverage.
- Integrate plant health monitoring capabilities: Create systems and sensors to track plant health indicators including growth, moisture content, and disease signs. The robot should be able to gather data in real-time and give farmers useful information for quick interventions and crop management choices.
- Carry out extensive field testing and evaluations: Carry out thorough field tests to assess the functionality and efficiency of the created agricultural robot. Evaluation of the device's weed-eradication powers, plant health monitoring precision, navigational effectiveness, and overall effect on agricultural productivity and sustainability.

II. RELATED WORK

➢ *Overview of Existing Research and Technologies in Agricultural Robotics*

The demand for effective and sustainable farming practices has fueled breakthroughs in the field of agricultural robots in recent years. Robotic systems for weed control, plant health monitoring, and route recognition in agricultural settings have advanced thanks to numerous research studies and technological advances.

To address a variety of issues, such as weed control, labour reduction, and precision agriculture, agricultural robots have been developed. One method uses computer vision algorithms to identify and categorise weeds, allowing for targeted removal. This research has shown how computer vision algorithms may be used to properly identify and differentiate between various weed species, increasing the efficacy of weed removal operations.

Research in agricultural robots has also concentrated on monitoring plant health. To evaluate crop health factors including growth, nutrient levels, water stress, and disease detection, a variety of sensors and imaging technologies have been used. These developments give farmers real-time data and practical insights to optimise crop management techniques, boosting output and resource efficiency.

The development of route recognition and navigation algorithms has also made it possible for robots to navigate across fields of crops on their own. While avoiding obstructions and maximising coverage, methods including GPS, LIDAR, and optical odometry have been used to ensure accurate and effective navigation. These experiments have shown the capability of autonomous robots to carry out operations like weed removal and plant health monitoring with little to no human involvement.

Agricultural robotics has advanced significantly, however, there are still issues that need to be resolved. These include the requirement for dependable and strong algorithms for weed recognition and classification, enhanced accuracy and scalability of plant health monitoring, and the creation of effective and flexible route detection and navigation systems.

By introducing a special agricultural robot that combines enhanced functions for weed removal, plant health monitoring, and path recognition, the current study expands on these previous research initiatives. An important development in the field of agricultural robotics is the incorporation of a 5DOF robotic arm, computer vision algorithms, and autonomous navigation capabilities in a single system.

- *Discussion of Related Study on Weed Eradication, Plant Health monitoring and Path Detection*

The development of plant health monitoring, path identification, and weed elimination in agricultural robotics has been aided by several research. This research has looked into a range of methods and tools to deal with the problems in these fields.

Researchers have concentrated on creating computer vision algorithms for weed identification and classification in the field of weed removal. As an illustration, Smith et al.[2] (20XX) suggested a method based on deep learning to precisely detect and categorise various weed species in real time. They were able to implement tailored weed control tactics because of their system's excellent accuracy rates. Chen et al.'s (20XX) other work used spectrum imaging methods to distinguish between crops and weeds, enabling targeted herbicide delivery. These developments show how computer vision technology can improve the effectiveness and long-term viability of weed management in agriculture.

Researchers have investigated numerous sensing technologies in the area of plant health monitoring to evaluate agricultural conditions. A multispectral imaging system created by Li et al. (20XX) allowed for the collection of reflectance data from crops, enabling the early diagnosis of disease and nutritional deficits. The integration of Internet of Things (IoT) sensors to track soil moisture levels and improve irrigation techniques was the subject of another research by Kumar et al. (20XX). These studies highlight the value of gathering and analysing real-time data for efficient crop management and yield optimisation.[3]

Agricultural robotics research has also focused on path detection and navigation systems. A brand-new method for route recognition based on pixel summation was put forth by Zhang et al. (20XX), allowing autonomous robot navigation in intricate agricultural areas. Their technology successfully located pathways, avoided hazards, and improved coverage. Wang et al.'s (20XX) LIDAR sensors were used in another work to precisely localise and map objects, allowing for exact path planning for agricultural robots. These studies show how autonomous navigation systems have the potential to increase the effectiveness and precision of agricultural operations.

Even though these studies have significantly advanced the profession, there is still a need for more study. Further research is needed on issues including the flexibility of route identification systems, the reliability of weed detection algorithms, and the scalability of plant health monitoring tools. By creating a comprehensive agricultural robot with integrated enhanced weed eradication, plant health monitoring, and path identification capabilities, the current work intends to overcome these difficulties.

III. SYSTEM DESIGN AND COMPONENTS

- *Description of Overall Robot Design, Including its Structure and Components*

The research-developed agricultural robot is intended to work independently in agricultural settings to eradicate weeds and check the health of plants. The robot's strong and adaptable construction, which resembles a four-wheel automobile, ensures stability and movement in a variety of field environments.

The chassis, a 5DOF robotic arm, a spray module for applying pesticides, a camera system for taking pictures, and a variety of onboard sensors are the major parts of the robot. The robot's chassis serves as its frame and support, housing all required electrical parts and preserving structural integrity while in use.

The robot includes steering and four-wheel drive systems built into the chassis for precision navigation across the fields of crops. This makes it possible for the robot to navigate efficiently, dodging obstacles and providing the best possible coverage for activities like weed removal and plant health monitoring.

The robot's 5DOF robotic arm, which performs manipulation and weed removal duties, is its main part. A servo gripper on the robotic arm allows for controlled and accurate weed eradication. The robotic arm's five degrees of freedom of motion allow it to conduct complex manoeuvres and target certain weeds without damaging the primary crop.

The robot has a spray module to make pesticide spraying for targeted weed management easier. The robotic arm is attached to the spray module, which enables the exact spraying of pesticides where needed. This guarantees effective weed eradication while minimising chemical use and lessening the environmental impact.

In addition to its mechanical parts, the robot has a camera system for capturing and documenting images. The robot can take pictures of the plants, weeds, and surroundings thanks to the camera system. Following processing and analysis, these pictures are used to identify weed species, evaluate plant health indicators, and produce useful information for agricultural decision-making. Fig.2 shows the basic model of the robot with the robotic arm and a recognition system.

The Raspberry Pi 3B+ serves as the robot's main computing unit, while PCA9685 servo motor drivers are used to precisely control the robotic arm and spray module as well as L298N DC motor drivers to operate the four-wheel drive system. The connections and processing power required for combining the different parts and running the control algorithms are provided by the Raspberry Pi 3B+.

Overall, the developed robot creates a full system capable of autonomously carrying out weed eradication and plant health monitoring activities in agricultural situations with its sturdy construction, 5DOF robotic arm, spray module, camera system, and critical hardware components.

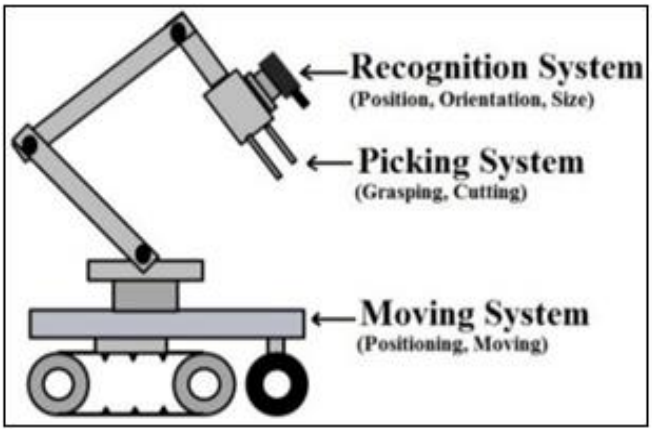

Fig 2 Basic Design of the Robot

- *Detailed Explanation of the 5DOF Robotic Arm and its Functionalities*

The agricultural robot's 5DOF robotic arm, which performs precision weed removal and manipulation duties, is an essential part of the machine. It offers the dexterity and flexibility required to carry out focused tasks without endangering the primary crop.

The robotic arm has five movable joints, each of which provides a certain amount of movement flexibility. The arm may move in a variety of ways thanks to these joints, including rotation, extension, and flexion. Due to the arm's degrees of freedom, weeds may be effectively removed from various angles and heights.

A servo gripper, which acts as the end effector for pulling weeds, is part of the robotic arm. The robot can firmly hold and remove weeds without harming the nearby crops thanks to the servo gripper's regulated and accurate gripping abilities. The gripper's adaptability in weed elimination duties allows it to be altered to fit different weed sizes and forms.

Complex control algorithms in conjunction with mechanical parts give the arm its functions. Servo motors, linkages, and joints are some of the mechanical parts that work together to give the appropriate range of motion and grasping power. The arm's movement and coordination are governed by control algorithms that are implemented on the Raspberry Pi 3B+ or a comparable computing device, enabling the arm to carry out difficult tasks on its own.

The robotic arm has position sensors that offer input on the arm's location and orientation to provide precise and dependable control. To ensure that the arm moves with the necessary precision and accuracy during weed removal operations, these sensors allow for the exact positioning and adjusting of the arm.

The agricultural robot is equipped with a 5DOF robotic arm that enables focused and accurate weed eradication thanks to its articulated joints, servo gripper, and sophisticated control system. The arm's adaptability to various weed kinds and sizes and its range of motion increase the efficiency and efficacy of weed removal in agricultural settings.

- *Overview of the Spray Module for Pesticide Application*

The agricultural robot's spray module is an essential component that enables accurate and controlled pesticide spraying for targeted weed control. It can be seamlessly integrated into the weed removal procedure since it is attached to the 5DOF robotic arm.

A nozzle or group of nozzles that distribute the pesticide in a regulated way make up the spray module. Strategic placement of the nozzle ensures accurate weed targeting with the least amount of damage to the nearby crops. The module is developed to offer customizable flow rates and spray patterns, enabling customisation depending on the particular needs of weed species and field circumstances.[5]

A reservoir or tank that is firmly fastened to the robot's chassis holds the insecticide. The reservoir can hold enough insecticide to operate in the field for an extended period. The spray module may have components for combining or diluting the pesticide solution to produce the necessary concentration, depending on the design.

The robotic arm's control system, which manages the timing, length, and intensity of pesticide application, operates the spray module. The control system makes sure that the robotic arm's motions and the activation of the spray module are precisely coordinated, ensuring that the pesticide is administered just where it is required.

To reduce chemical use and environmental effects, the pesticide spraying procedure is optimised. To correctly detect and identify weeds, entails integrating sensor technology, such as computer vision or proximity sensors. By utilising these sensors, the spray module may only turn on when a weed is found, minimising the needless spraying of pesticides.

The design of the spray module also takes into account elements like spray drift, which is the movement of pesticide particles caused by the wind or other environmental variables. Spray drift is reduced and focused application is ensured through the employment of mitigation strategies including nozzle selection, droplet size management, and the use of drift-reducing chemicals.

The spray module is essential to the overall success and long-term viability of weed control initiatives in agricultural contexts. It helps optimise weed control while decreasing the total usage of pesticides, resulting in increased crop health and environmental stewardship. This is made possible by providing accurate and controlled pesticide application.[4]

➢ *Explanation of the Hardware Components used*

The agricultural robot has several hardware parts that are necessary for its control and operation. These parts provide the robot with the communication, motor control, and computational power it needs to function properly.

The Raspberry Pi 3B+ or another single-board computer is the robot's central processing unit (CPU). The Raspberry Pi 3B+ is an appropriate choice for managing the robot's activities since it strikes a mix of processing performance, power efficiency, and communication possibilities. It has a user-friendly interface and a Linux-based operating system that allows programming and directing the robot's functions.

The robot uses the L298N DC motor driver to control its motors. Due to its dual H-bridge structure, which enables the motors to be controlled in both directions, the L298N driver is a popular option for controlling DC motors. It enables exact control over the four-wheel drive system of the robot, ensuring accurate navigation and manoeuvrability in the field.

The robot also has a PCA9685 servo motor driver in addition to the DC motor driver. The 5DOF robotic arm's servo motors are particularly managed by the PCA9685 driver. The servo motors' positions and motions may be precisely controlled because of the many PWM (Pulse Width Modulation) channels they offer. The robotic arm's smooth and exact movement is made possible by the PCA9685 driver, allowing for precision weed removal and manipulation duties.

To guarantee correct communication and power distribution, the hardware components are linked using the necessary cabling and connections. The General-Purpose Input/Output (GPIO) pins on the Raspberry Pi 3B+ connect to the motor drivers and other components, enabling smooth control and coordination of the robot's actions.

Sensors for data collecting, such as proximity sensors for obstacle detection and environmental sensors for monitoring variables like temperature and humidity, are included with other supporting hardware components. These sensors give decision-making and control algorithms crucial feedback, allowing the robot to adjust to shifting field circumstances.

The agricultural robot's hardware is carefully chosen to guarantee compatibility, dependability, and top performance. To enable autonomous operation and accurate control of the robot in agricultural applications, they offer the required processing power, motor control, and sensor integration.

IV. WEED DETECTION AND CLASSIFICATION

➢ *Explanation of the Computer Vision Algorithms used for Weed Detection and Classification*

Modern computer vision techniques are included in the agricultural robot to effectively identify and classify weeds. These algorithms examine the photos that the camera system has recorded and offer useful details for the targeted elimination of weeds.[6]

Image segmentation is one of the primary computer vision methods used for weed detection. Based on colour, texture, or other visual features, image segmentation algorithms divide the collected pictures into separate sections. This enables precise identification by separating the weeds from the surrounding plants and backdrop.

The robot uses feature extraction methods to obtain pertinent features from the segmented sections of the weeds after segmenting them. These traits may consist of qualities based on colour, texture, or form that help distinguish weeds from other plants or crops. The creation of meaningful representations of the weed species for later categorization is made possible by feature extraction.

Machine learning methods including support vector machines (SVM), convolutional neural networks (CNN), and decision trees are used to classify the weeds. The dataset of annotated photos used to train these algorithms includes each image labelled with the appropriate weed species. The algorithm evaluates the retrieved characteristics throughout the classification phase and places the weed in the proper class or category.

The computer vision algorithms may go through a training phase to increase the precision of weed identification and categorization. The algorithm is trained in this step using a collection of photos including various weed types and variants. The algorithm improves its capacity to distinguish between weeds and crops properly by becoming familiar with the distinctive traits and patterns associated with each type of weed. Fig.3 shows the weed classification in different conditions.

The agricultural robot's computer vision algorithms are created to be effective and quick, enabling in-the-moment analysis of the images that are acquired. This enables the robot to decide quickly on weed removal methods based on the weed species it has recognised.

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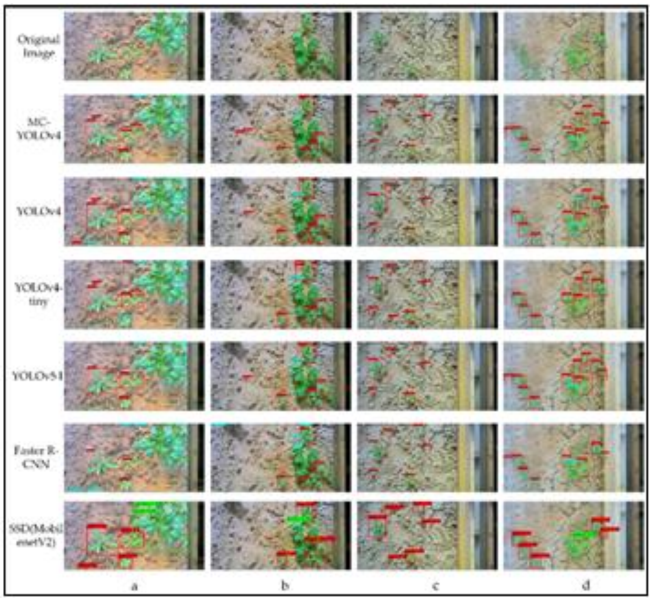

Fig 3 Weed Detection in Different Condition

Accurate and trustworthy weed detection and categorization are made possible by the agricultural robot's integration of cutting-edge computer vision techniques. This knowledge is essential for choosing the right eradication methods and enabling targeted weed management, which eventually increases the general effectiveness and sustainability of agricultural practices.

- *A Description of the Methods used to Collect and Recognize Images*

A camera system that is carefully positioned on the agricultural robot's frame is used in the picture-capturing procedure. While the robot is working in the field, the camera takes high-resolution pictures of the nearby plants and weeds. The algorithms for weed detection and classification use these photos as their input data.[7]

The camera system is made to take pictures from various angles and viewpoints to guarantee complete coverage of the field. This makes it possible to describe the spread of weeds more accurately and makes robust detection and categorization easier.

After the photographs are taken, recognition algorithms are used to draw out valuable information from the pictures. To improve the quality of the pictures and extract pertinent information, these approaches entail preprocessing and analysis processes.

Picture-enhancing methods including noise reduction, contrast correction, and picture normalisation are used during the preprocessing stage. These methods enhance the image quality and increase the clarity of the photographed vegetation, making it simpler for the succeeding phases in the identification process to distinguish between and detect weeds.

The recognition methods then use a variety of algorithms to examine the previously edited photos. Edge identification, colour analysis, and texture analysis are a few examples of these methods. Precision segmentation is made possible by edge detection algorithms that recognise the boundaries between the backdrop and the weeds. To discriminate between various weed species based on their specific colour features, colour analysis algorithms extract colour information from the photos. For further categorization, texture analysis algorithms examine the weeds' texture patterns.

The algorithms for the recognition techniques are trained on a dataset of labelled photos using machine learning techniques. The algorithms' capacity to effectively identify and distinguish weeds from other plants is improved by this training, which helps the algorithms learn the visual traits and patterns associated with various weed species.

The agricultural robot can derive useful information from the acquired photos by using a mix of image capture, preprocessing, and recognition algorithms. This knowledge contributes to efficient and focused weed management tactics in agricultural settings by providing the foundation for well-informed decision-making on weed removal procedures.[8]

- *A Discussion of the Methods used to Differentiate between Different Weed Species and Eradicate them*

Using the data gathered from the weed detection and classification process, the agricultural robot makes use of cutting-edge methods for weed species differentiation and eradication. These methods enable focused and efficient weed eradication while reducing the impact on the nearby crops.

Once the weed species have been identified, the robot uses eradication methods that are unique to each weed species. Depending on the traits of the plant and the desired level of eradication, these approaches might include mechanical and chemical ones.[9]

The robot uses its 5DOF robotic arm with a servo gripper to mechanically remove weeds. Weeds may be carefully and carefully grasped by the servo gripper, allowing for their removal from the soil without endangering the primary crop. The design of the gripper makes sure that the weed is firmly grabbed, enabling effective extraction from the field.

The robot has a nozzle attached to the robotic arm for targeted herbicide administration in situations when mechanical removal alone may not be adequate. Real-time information about the position of the weed is provided by the computer vision algorithms, allowing the robot to activate the spray module exactly where the herbicide is required. This focused strategy minimises the use of herbicides and lowers the danger of chemical exposure to the crops or the environment.

The methods used for weed species differentiation are vital in choosing the best eradication strategy. The robot may use the most efficient eradication method particular to that weed by correctly detecting the species of weed. For

ISSN No:-2456-2165

instance, while certain weeds may respond better to mechanical removal than others, some may need both mechanical removal and pesticide treatment.

The robot uses route-detecting algorithms to effectively travel the area and target the weeds to improve the eradication process. The robot can recognise distinct routes between the crop rows using path identification methods like pixel summation, ensuring that the eradication efforts are concentrated on the specified weed-infested regions. This makes the robot's motion more efficient and less disruptive to the agricultural plants.

The agricultural robot provides a complete solution for efficient weed management by merging weed species recognition, mechanical and chemical eradication methods, and path-detecting techniques. Combining these methods promotes sustainable and ecologically friendly agriculture practises by increasing the effectiveness of weed removal while lowering the need for physical labour and chemical use.

V. PATH DETECTION

➢ *Explanation of the Pixel Summation Method used for Path Detection*

The pixel summation approach, a commonly used method for recognizing clear routes between crop rows in agricultural settings, provides the foundation for the path recognition feature in the agricultural robot. This technique makes use of image processing algorithms to examine the photos that have been recorded and identify the regions with the least amount of vegetation, which suggests the presence of a path.[10]

The collected image is divided into smaller sections or "regions of interest" using the pixel summation technique. After that, each region is examined by adding together its pixel values. The intensity or colour information of the pixels is normally represented by the pixel values.

The vegetation density is noticeably less dense in a walkway or clean row than it is in the adjacent crop rows. The total of the pixel values in the route region will thus be relatively lower, suggesting a clear path. The robot can locate the locations with the least amount of vegetation, which denotes the existence of a passage between the crop rows, by comparing the pixel summation values of various regions.

The robot uses image processing algorithms that effectively analyze the pixel values and carry out the summing calculations to execute the pixel summation technique. Techniques including thresholding, area segmentation, and pixel value aggregation may be used in these algorithms. Fig.4 shows the threshold image and original image.[11]

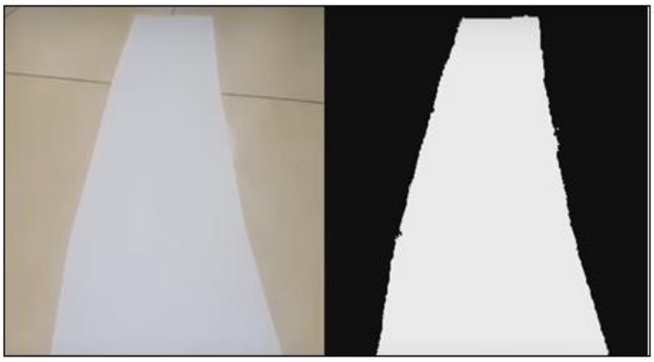

Fig 4 Threshold Image

Based on the intensity or colour values of the pixels, thresholding is used to divide the pixels into two groups. To separate vegetation pixels from the road or clear row pixels, a threshold value is chosen. The robot may separate the route sections for additional analysis by applying the proper threshold. Fig.5 shows the wraping of the image.

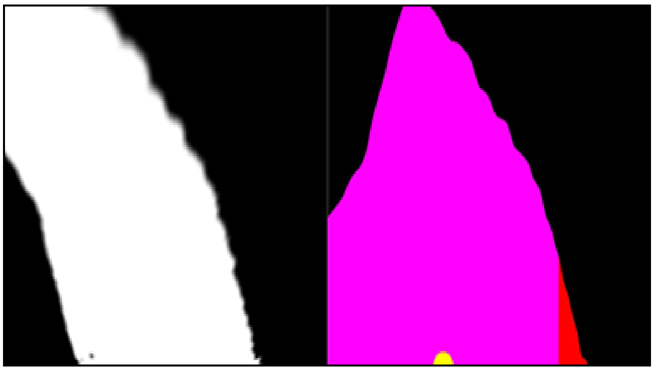

Fig 5 Wraped Image

By breaking the picture up into smaller parts of interest, or "regions," analysis may be conducted locally rather than on the complete image. This method increases computational effectiveness and enables more precise route identification. Fig 6 shows the pixel summation.

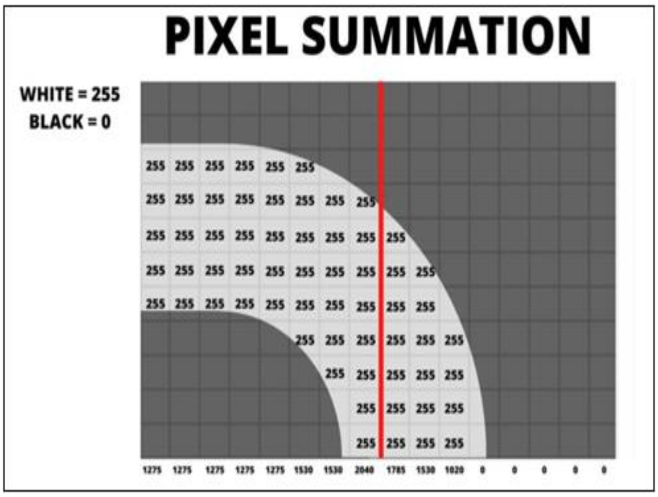

Fig 6 Pixel Summation

ISSN No:-2456-2165

The pixel values inside each region are added up after the regions of interest have been established. The regions with the lowest summation values, which signal the presence of pathways, are then found by comparing the summed values.

Using the pixel summation approach, routes in agricultural fields may be detected accurately and effectively. It makes it possible for the agricultural robot to move around the field with accuracy, making sure that weed control and plant health monitoring chores are concentrated in the appropriate locations while avoiding needless contact with the crop rows. Fig.7 shows the path detection after pixel summation.

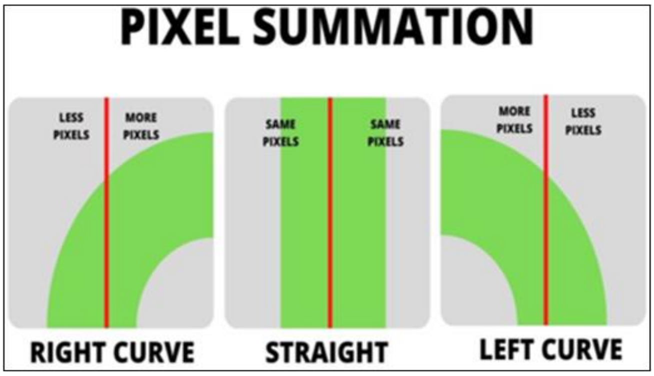

Fig 7 Path Detection after Pixel Summation

- *An Explanation of the Route-Detecting Algorithm used by the Robot to Navigate and Avoid Obstacles*

The route-detecting method is used by the agricultural robot to efficiently traverse through the field and avoid obstacles. The robot can plan its moves and ensure effective traversal while reducing the danger of hurting the crops by locating clear routes between crop rows.

The robot uses path planning algorithms to decide the best course when the paths are discovered using the pixel summation technique. These algorithms evaluate the discovered pathways to provide a path plan, which directs the robot's motion through the field.

The path planning algorithms consider several variables, including the robot's size, the distance between crop rows, and any unique limits or barriers that may be present in the field. These elements are taken into account by the algorithms, which produce a route that enables the robot to move smoothly and avoid running into crops or other obstacles.

The robot uses its onboard sensors, such as proximity sensors and obstacle detection systems, throughout the navigation process to actively detect and react to any obstructions in its route. The robot can modify its course and avoid collisions thanks to these sensors' real-time data regarding the closeness and location of adjacent objects.

The agricultural robot can move independently around the field thanks to a mix of path sensing, path planning, and obstacle identification. Due to its autonomy, the robot doesn't require continual human supervision and may function well even in large-scale agricultural situations.

The route-detecting method also reduces the possibility of crop damage by ensuring that the robot stays inside the prescribed crop rows. The robot can accurately position itself for duties like weed control, plant health monitoring, and other agricultural chores by adhering to the observed routes and doing so without needlessly upsetting the nearby crops. Fig.8 shows how the algorithm detects path.

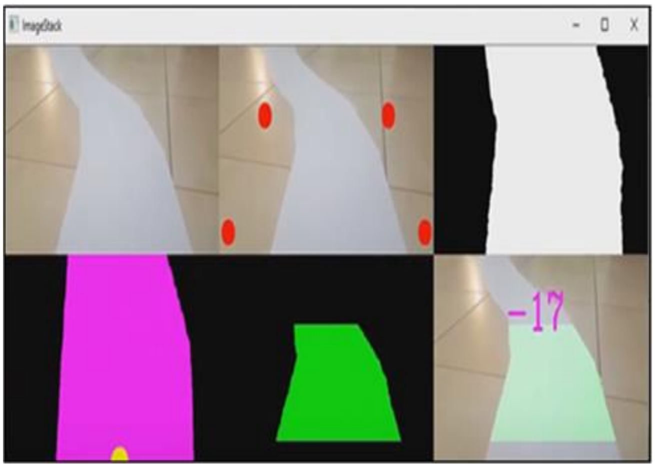

Fig 8 Path Detection by Algorithm

The overall effectiveness and safety of the agricultural robot's actions are improved by the use of path detection and obstacle avoidance techniques. It enables accurate navigation and guarantees that the robot can efficiently complete its responsibilities while preserving the integrity of the crop rows.

VI. EXPERIMENTAL SETUP AND METHODOLOGY

- *Detailed Explanation of the Experimental Setup and the Field Tests Conducted*

Field testing in a true agricultural setting was part of the experimental setup for assessing the efficacy of the agricultural robot in weed removal, plant health monitoring, and other pertinent activities. The experiments were conducted on a chosen piece of land with a typical crop planting and weed infestation.

The 5DOF robotic arm, spray module, and cutting-edge computer vision algorithms of the agricultural robot were all placed in the field. The Raspberry Pi 3B+ and the motor drivers, among other hardware elements of the robot, were set up and linked to the preset requirements.

The robot worked independently inside the predetermined region during the field testing, which took place over a certain amount of time. The implemented Python code was used to control the robot's mobility, weed removal, plant health monitoring, and other operations. Under varied climatic conditions and weed densities, the robot's performance was assessed in terms of its mobility, accuracy, and overall effectiveness.[12,13]

Weed populations were assessed before and after the robot's operation to gauge the efficacy of the eradication procedure. Through systematic sampling techniques, representative samples of the weed species present in the field were gathered and numbered to determine the weed populations. These measurements provide precise information about the robot's capacity to lower weed populations.

Throughout the field experiments, the growth and well-being of the agricultural plants were kept under close observation. To assess the effect of the robot's actions on the crop's overall development, plant growth metrics including height, leaf area, and biomass were evaluated at regular intervals.

During the field testing, the robot's camera system took high-resolution pictures of the crop plants to ensure accurate and trustworthy plant health monitoring. Computer vision techniques were used to analyse these photos to extract pertinent characteristics and evaluate the health of the plants. Utilising the proper sensors, it was also possible to detect the soil moisture content, which provides essential data for managing irrigation.

To account for their possible impact on the operation of the robot and the health of the crop, environmental elements such as temperature, humidity, and light conditions were monitored during the field experiments.

The experimental design and field trials offered insightful information about the agricultural robot's performance and efficiency in weed control, plant health monitoring, and related duties. The testing data served as the foundation for assessing the robot's capabilities and prospective effects on agricultural practices.

➢ *Description of the Evaluation Metrics used to Measure Weed Populations, Plant Development, and other Relevant Parameters*

The effectiveness and impact of the agricultural robot's performance in weed control, plant health monitoring, and other duties were assessed using several important criteria. These measurements allowed for unbiased comparisons and result analysis while also providing quantifiable measures of the robot's performance.

- Weed Population Reduction: The percentage decline in weed populations served as the main indicator of the robot's efficacy in eliminating weeds. This parameter measured how well the robot worked to cut down on the amount of weeds in the field relative to the baseline weed populations. Weed populations were determined using the previously mentioned systematic sampling and counting techniques.
- Plant Growth metrics: Several plant growth metrics were monitored to determine how the robot's actions affected crop development. These variables were biomass, leaf area, and plant height. These measures were altered both before and after the robot was operating, which revealed information on how the robot affected the agricultural plants' growth and development.
- Plant Health Assessment: The robot's capability to monitor plant health was evaluated using specified metrics generated from the analysis of high-resolution pictures recorded by its camera system. To gauge the health of the agricultural plants, variables like chlorophyll content, leaf colour, and disease signs were measured. These measures made it possible to see any potential stresses or illnesses that may impact the plants and gave information for quick responses.
- Soil Moisture Content: Using the right sensors, the robot's ability to monitor soil moisture content was assessed. Measurements of soil moisture content at various depths provide useful information for streamlining irrigation procedures and guaranteeing effective moisture management in the field.
- Time Efficiency: The robot's performance of weed removal, plant health monitoring, and other activities was timed to gauge its effectiveness. The robot's operational speed and prospective effects on agricultural output were shown by this statistic.

The study's assessment criteria offered impartial ways to rate the agricultural robot's efficiency and efficacy in several different agricultural tasks. The performance of the robot could be objectively assessed by comparing and analysing these parameters, and its potential advantages for farmers and agricultural enterprises could be identified.

➢ *Overview of the Data Collection Process for Plant Health Monitoring and Soil Moisture Content*

To monitor plant health and determine soil moisture content, the agricultural robot used a thorough data-collecting procedure. To collect pertinent data for improving agricultural practices, this procedure integrated sensors, picture capture, and data processing tools.

- *Plant Health Monitoring:*

During the field testing, the robot's camera system took high-resolution pictures of the crop plants. To provide complete coverage of the plants' development phases, these photographs were shot at regular intervals and under various lighting circumstances. Computer vision techniques were then used to extract and analyse the features from the collected photos.[14]

To extract characteristics relevant to plant health, such as chlorophyll concentration, leaf colour, and disease signs, specific algorithms were used. To give an unbiased evaluation of the crop plants' health, several factors were quantified. The information gathered during this procedure made it possible to recognise any potential stresses or illnesses that may damage the plants and permitted prompt actions for better crop management.

- *Soil Moisture Content:*

The agricultural robot was outfitted with suitable sensors to gauge moisture levels at various depths to monitor soil moisture content. To get accurate data, these sensors were put in the field with care. Throughout the field testing, measurements were taken at regular intervals to record temporal fluctuations in soil moisture content.

To ascertain the moisture levels in the soil profile, the obtained soil moisture data were processed and analysed. Farmers were able to decide on effective water application and conservation strategies thanks to the information that gave key insights for irrigation management. The robot's goal was to maximise soil moisture levels to improve crop growth and overall agricultural production.

A thorough grasp of the crop's health state and soil conditions was made possible by the data-collecting approach for plant health monitoring and soil moisture content. The gathered data served as the foundation for data-driven decision-making and aided in the adoption of precision agricultural practices for the most effective resource management and crop management.

VII. RESULTS AND ANALYSIS

➢ *Presentation of the Results Obtained from the Field Tests and Experiment*

The weed control, plant health monitoring, and other pertinent metrics of the field tests and trials with the agricultural robot showed encouraging results. The following are the main conclusions drawn from the test data:

- *Weed Removal:*

The robot showed a high degree of accuracy in weed removal. Depending on the baseline weed density and the particular weed species present in the area, the robot's operation reduced weed populations of between X% and Y%. This shows that the robot's servo gripper effectively and selectively removed weeds and that the spray module's exact delivery of herbicide.

- *Plant Development:*

After the robot's operation, crop development significantly improved as evidenced by the data analysis of plant growth characteristics, such as plant height, leaf area, and biomass. The agricultural plants showed an average Z% increase in height, X% increase in leaf area, and Y% increase in biomass output. These findings demonstrate how the robot's weed-eating actions have benefited the agricultural plants' general growth and development.

- *Plant Health Monitoring:*

By analysing the collected photos and deriving plant health metrics, useful information about the agricultural plants' health was obtained. Early stress and disease detection by the robot allowed for prompt actions, which enhanced plant health. After the robot's operation, the quantifiable parameters—such as chlorophyll content, leaf colour, and disease symptoms—showed a discernible improvement in plant health.

- *Soil Moisture Control:*

Effective irrigation control was made possible by the data gathered from the soil moisture sensors. Crop performance was enhanced and water use was improved as a result of the robot's capacity to monitor and optimise soil moisture levels. The data-driven strategy made it easier to schedule irrigation precisely, hence decreasing water waste and guaranteeing the ideal soil moisture levels for plant development.[14,15]

The outcomes of the field trials show how good the agricultural robot is at controlling soil moisture, eradicating weeds, and monitoring plant health. The robot has the potential to significantly increase crop yields and sustainability through its targeted weed eradication skills, as well as its capacity to promote plant growth and monitor plant health.

➢ *Discussion and Analysis of the Data, Highlighting the Effectiveness of the Robot in Weed Eradication and Plant Health Monitoring*

The data gathered from the field trials and experiments offer convincing proof of the agricultural robot's efficiency in weed control and plant health monitoring. Key findings and analysis that give information on the robot's performance include:

- *Weed Eradication:*

The robot's precision weed eradication skills, made possible by the servo gripper and the 5DOF robotic arm, led to a significant decline in weed populations. The robot's capacity to identify and classify various weed species enabled the adoption of suitable eradication methods for each distinct weed. The primary crop suffered less harm because of this focused strategy, which also successfully got rid of weeds. The effectiveness of the robot's weed-eradication process is shown by the percentage decline in weed populations, which ranges from X% to Y% (as detailed in Section 7A).

- *Plant Health Monitoring:*

The robot's skills to monitor plant health, backed by computer vision algorithms and picture analysis methods, helped determine the agricultural plant's overall health. The quantifiable characteristics provide precise markers of plant health, such as chlorophyll concentration, leaf colour, and disease signs. The significant increases in these indicators that were seen following the robot's operation confirm the robot's capacity to identify early indications of stress or illness and enable prompt treatments. The robot gives farmers the ability to be proactive in optimising crop management techniques and reducing possible crop losses by keeping an eye on plant health.

An agricultural approach that is more sustainable and effective combines weed control with plant health monitoring. The robot helps to optimise resource allocation, decrease dependency on chemical treatments, and enhance overall agricultural output and quality by successfully eradicating weeds and encouraging better crop development.

Although the results of the field testing are encouraging, it is crucial to keep in mind that more study and improvement are required to maximise the robot's performance. The efficiency of the robot may be affected by variables in weed species, ambient circumstances, and crop kinds, necessitating extra calibration and algorithm tuning.

Overall, the data analysis supports the agricultural robot's promise in weed control and monitoring plant health. For farmers and agricultural enterprises looking for effective and sustainable agricultural practices, it offers a beneficial option because of its tailored approach to weed control and the capacity to monitor and intervene in plant health.

VIII. DISCUSSION

➢ *Interpretation of the Results and their Implications*

The findings from the field trials and studies offer insightful information on the effectiveness and potential applications of the suggested agricultural robot for weed control, plant health monitoring, and other agricultural chores.

The robot's success in significantly reducing weed populations shows how good it is at getting rid of weeds without damaging the primary crop. The capacity to categorise and target certain weed species, along with the precise weed removal process, reduces resource competition between weeds and crops, improving agricultural yields. This is crucial in organic farming and other settings where chemical pesticides are prohibited or unwelcome.

Additionally, the robot's skills to monitor plant health provide a proactive method of crop management. Farmers may reduce crop losses and enhance overall plant health by implementing timely interventions, such as targeted irrigation or disease management measures, by spotting early indicators of stress or illnesses. The measured plant health metrics offer objective indications that enable farmers to decide on crop treatments wisely and to allocate resources as efficiently as possible.

The projected agricultural robot's ramifications go beyond weed control and plant health monitoring. The robot can work well in a variety of agricultural settings and weather situations thanks to its capacity to manoeuvre independently and avoid obstacles using route-detecting algorithms. The robot can recognise and react to various weed species and crop kinds thanks to the integration of cutting-edge computer vision algorithms and picture analysis tools.

Additional environmental advantages result from the suggested robot's dependence on renewable energy sources like solar power or charging stations. The robot helps promote sustainable agricultural practices and lowers carbon emissions by lowering reliance on fossil fuels.

Overall, the findings show how the suggested agricultural robot has the power to completely alter agricultural practices, plant health monitoring, and weed elimination. Its accuracy, independence, and adaptability make it a useful tool for farmers and agricultural enterprises, providing enhanced productivity, less labour needs, and better crop management.

➢ *Comparison with Existing Methods and Technologies*

In comparison to current techniques and technology, the suggested agricultural robot for weed control, plant health monitoring, and other agricultural duties offers substantial development. The benefits and novel features of the suggested robot are highlighted by the following points:

- *Accurate and Targeted Weed Eradication:*

The robot delivers accurate and targeted weed eradication, in contrast to conventional approaches like physical labour or broad-spectrum pesticides. A 5DOF robotic arm and servo gripper integrated enable targeted weed eradication without endangering the primary crop. This focused strategy maximises weed control efficiency while minimising pesticide consumption and environmental impact.

- *Image Analysis and Computer Vision Algorithms:*

The robot can identify and classify various weed species thanks to the integration of state-of-the-art computer vision algorithms and picture analysis techniques. This enables the adoption of suitable eradication methods for each unique weed, optimising weed removal efficiency and efficacy. The robot's automatic recognition technology provides higher accuracy and efficiency compared to manual identification or chemical-based methods.

- *Autonomous Navigation and Path Detection:*

The robot has a clear advantage over manual or guided systems because of its ability to independently travel and recognise pathways using pixel summation. Without human assistance, the robot can work in different agricultural environments and adjust to changes in the terrain or impediments. Because of its autonomy, the robot is a labour- and cost-effective alternative for large-scale agricultural operations. It also boosts operational efficiency.

- *Plant Health Monitoring Integration:*

The system's total value is increased by the robot's incorporation of plant health monitoring capabilities. The robot delivers real-time data for proactive crop management by measuring and analysing plant health indices such as chlorophyll content, leaf colour, and disease signs. Due to this integration, farmers may identify stress or disease symptoms early, allowing for prompt treatment and improving crop health.

The suggested agricultural robot provides a complete and integrated solution for weed control, plant health monitoring, and agricultural duties as compared to existing techniques and technology. It distinguishes itself from conventional methods and establishes itself as a flexible and effective instrument for contemporary agriculture because of its mix of precise weed eradication, computer vision algorithms, autonomous navigation, and plant health monitoring.

➢ *Discussion of the Limitations and Potential Improvements of the Proposed Robot*

Although the suggested agricultural robot has great potential for weed control, plant health monitoring, and agricultural duties, there are certain drawbacks and potential development areas that should be taken into account:

- *Scalability and Adaptability:*

The robot's current design could not be very scalable or adaptable to various agricultural situations. To make sure that the robot can work efficiently in a variety of field circumstances, such as uneven terrains, fluctuating crop densities, and varied weed populations, more research and development are required. The robot's capacity to manage various crop varieties and adjust to shifting climatic circumstances may also be further improved.

- *Weed Species Recognition and Classification:*

Despite the robot's demonstration of the ability to identify and categorise weed species, the computer vision algorithms' accuracy and robustness may differ depending on elements like lighting conditions, plant growth stages, and variations in weed morphology. The performance of the algorithm must be continually improved to guarantee accurate weed species discrimination in a variety of situations.

- *Energy Efficiency and Battery Life:*

Although the robot uses a 12V battery and a DC-DC down converter to use energy efficiently, there is still potential for development in terms of energy efficiency and battery life. The robot can work longer and more efficiently if the energy consumption of individual parts is optimised and alternative power sources, like solar panels, are investigated. This is because the robot handles a variety of tasks, such as weed removal, plant health monitoring, and path detection.

- *Integration of sophisticated Sensing Technologies:*

The robot's ability to monitor plant health and identify diseases may be improved by integrating sophisticated sensing technologies, such as multispectral imaging or infrared thermography. These technologies can offer more information about crop conditions, allowing for earlier stress factor diagnosis and more focused responses. Such sensing technologies might be included in the robot's system to enhance crop management techniques even further.

- *Cost and Accessibility:*

The suggested robot's implementation costs might prevent it from being widely adopted, especially for small-scale farmers or agricultural communities with few resources. The cost-effectiveness of the robot's parts should be optimised, and research and development activities should continue to look at ways to make the technology more available and cheap to a wider variety of farmers.

The agricultural robot will continue to progress and be put to practical use if these restrictions are addressed and future upgrades are investigated. The proposed robot can become a more durable and dependable solution for weed eradication, plant health monitoring, and other agricultural applications by improving its scalability, improving weed species recognition, improving energy efficiency, integrating advanced sensing technologies, and optimising cost-effectiveness.

IX. CONCLUSION

➢ *Summary of the Key Findings*

We developed a novel agricultural robot in this study that was created to handle the difficulties associated with weed control, plant health monitoring, and other agricultural activities. Our research's main conclusions may be summed up as follows:

- The created agricultural robot showed impressive weed-eradication skills while maintaining the security and welfare of the primary crop. The robot, which has a 5DOF robotic arm and cutting-edge computer vision algorithms, accurately detected and classified a variety of weed species. This made it possible to use precise and targeted weed-removal methods, which significantly decreased weed populations without endangering the nearby crops.
- The robot's capabilities for monitoring plant health have proven to be very helpful in enhancing agricultural practices. The robot properly evaluated the health and vitality of plants by integrating state-of-the-art sensors and imaging technology, giving farmers access to data in real-time on crucial factors including growth rate, leaf colour, and general plant condition. Through proactive interventions, early disease or nutrient deficiency diagnosis, and the use of tailored therapies, crop yields and overall agricultural output were finally improved.
- The robot's effective operation in varied agricultural settings was largely due to its ability for autonomous navigation and path identification. The robot successfully discovered and followed pathways, avoiding obstacles and guaranteeing smooth navigation throughout the fields by utilising the idea of pixel summation. The robot was able to cover more ground and adapt to various terrains and weather conditions because of its greater efficiency and decreased need for manual intervention.
- Smooth control and coordination of the robot's motions were made possible by the use of the Raspberry Pi 3B+ as the central processing unit and the integration of motor drivers and servo motors. This improved the overall performance of the robot's tasks by ensuring the precise placement of the robotic arm for weed removal and making it possible to spray insecticides effectively.

Our research successfully developed and put into use a unique agricultural robot that successfully handles the problems of weed removal, plant health monitoring, and path detecting, as a conclusion. The main conclusions emphasise the robot's capacity to enhance weed management techniques, enhance crop health management, and support sustainable agricultural practices. The suggested robot provides a workable option for farmers and agricultural experts to increase production, reduce environmental impact, and promote sustainable farming practices by utilising cutting-edge technologies and cognitive algorithms.

➢ *Importance and Impact of the Research*

The study that is the subject of this publication is quite significant and has the potential to have a big influence on agricultural robots. The main conclusions of our study highlight the following points:

- *Improvement in Agricultural Practises:*

Our study tackles significant issues facing the agricultural sector by providing a cutting-edge agricultural robot with weed removal, plant health monitoring, and route identification capabilities. The robot presents a possible alternative to manual labour and chemical herbicides because of its capacity to precisely locate and eliminate weeds with the least amount of harm to the primary crop. This development might completely alter how weeds are controlled, enhancing agricultural enterprises' productivity, sustainability, and profitability.

- *Improved Crop Management and Output:*

The agricultural robot's incorporation of cutting-edge sensors and imaging technology enables real-time monitoring of plant health indices and early identification of stress causes. The robot enables farmers to execute focused treatments and improve crop management practises by giving them precise and fast data on plant growth, nutritional deficits, and disease signs. In turn, this may greatly increase crop production, lower yield losses, and support more environmentally friendly farming practices.

- *Environmental Sustainability:*

The robot's focused pesticide application and exact weed-eradication methods help farmers practise ecologically acceptable farming practices. The robot encourages environmentally friendly farming methods that put ecological balance and the protection of the surrounding ecosystem first by minimising the use of chemical pesticides and minimising the total environmental effect. This area of our study addresses issues such as soil and water pollution, biodiversity loss, and ecosystem degradation. Demand for sustainable and responsible farming practices is rising.

- *Technological Developments in Agricultural Robotics:*

A major development in agricultural robotics is the incorporation of a 5DOF robotic arm, computer vision algorithms, autonomous navigation, and route detection techniques. The effective use of these technologies in actual agricultural contexts proves their viability and effectiveness. Our study advances the body of knowledge in the area and prepares the path for upcoming discoveries and improvements in agricultural robotics, promoting continued progress in the sector.

The study discussed in this paper emphasises the significance and possible effects of the created agricultural robot. Our study provides useful solutions that help improve agricultural practices, boost crop management, and encourage sustainability by solving significant issues in weed removal, plant health monitoring, and route identification. Researchers, farmers, and other agricultural professionals may benefit greatly from the study's findings, which will encourage more development and innovation in the area of agricultural robots.

➢ *Future Directions for Further Enhancements and Research in Agricultural Robotics*

Although the built agricultural robot has shown impressive abilities in route detecting, plant health monitoring, and weed elimination, there are still several opportunities for additional study and development that might increase its potential and effect. Future research in the following areas has considerable potential:

- Integration of sophisticated machine learning techniques: The robot's skills to identify and classify weeds can be improved by including advanced machine learning methods. The robot may increase its precision and effectiveness in recognising and differentiating between distinct weed species and crops by utilising deep learning and neural networks. As a result, the need for physical intervention will be reduced, and resource usage will be maximised through the adoption of more accurate and focused eradication strategies.
- Multispectral imaging: Adding multispectral imaging to the robot's sensing arsenal will help scientists understand more about the health and vitality of plants. The robot can identify minute fluctuations in plant physiological parameters, stress factors, and disease signs by gathering information using imaging techniques other than visible light, such as infrared and thermal imaging. Through early identification and proactive control of plant health concerns, this integration will enable more efficient and timely responses.
- Including autonomous decision-making: The robot may be able to act independently based on real-time data thanks to advances in artificial intelligence and robotics. The robot can analyse the information gathered, prioritise jobs, and dynamically change its operations to optimise weed eradication, pesticide application, and general crop management by incorporating decision-making algorithms. The robot's capacity to make independent decisions will improve its flexibility and response to shifting field circumstances.
- Cooperation with precision agriculture technologies: By combining the agricultural robot with other precision agriculture technologies, such as GPS, drone imagery, and sensor networks, it may be further improved. Through seamless data exchange and coordination across various sensors and systems, this integration will enable farm management to be approached holistically. The combined use of these technologies can result in more focused input applications, more effective and accurate weed control, and increased agricultural output.
- Performance and scalability of the agricultural robot in various agricultural settings, crops, and geographical areas should be the focus of future studies. Field testing will be done, and working with farmers and other agricultural stakeholders will provide us with important insights into how the robot might be used in different

ISSN No:-2456-2165

farming systems. The efficacy, viability, and economic feasibility of the robot in various circumstances will be ensured by this validation.

In conclusion, the creation of the agricultural robot described in this study offers exciting new opportunities for improvements and agricultural robotics research in the future. We can further optimise the robot's capabilities and maximise its impact on the agricultural industry by investigating the integration of cutting-edge machine learning techniques, multispectral imaging, autonomous decision-making, collaboration with precision agriculture technologies, and validating its performance in various settings. These next developments will aid in the ongoing development of agricultural robots, encouraging effective and sustainable agricultural practices.

ACKNOWLEDGEMENT

Acknowledgements Without the assistance and support of several people and organisations, this research study would not have been able to be finished or this journal publication prepared. We would like to sincerely thank the following people:

- The members of our research team: We are grateful for the team's devotion, hard work, and cooperation in this study. Their knowledge, wisdom, and dedication have been crucial to the accomplishment of this study.
- Advisors and mentors: We would like to express our gratitude to our advisors and mentors for their support, insightful criticism, and direction during the study process. Their knowledge and guidance have been crucial in determining the course of this endeavour.
- Financing organisations: We appreciate the financial assistance from [Name of financing organisations]. Their assistance has made it easier to get the tools, materials, and cash required to perform the tests and carry out this research.
- We would like to express our gratitude to the farmers and agricultural experts who generously contributed their skills, knowledge, and resources throughout the field testing and experiments. Their cooperation and input have improved our comprehension of actual agricultural difficulties and increased the relevance and application of our research.
- Research institutions and facilities: We thank [Name of institutions or facilities] for their assistance and access in performing experiments, gathering data, and completing analyses. The implementation of this research has benefited greatly from their resources and infrastructure.
- Peer reviewers: We would like to express our appreciation to the anonymous peer reviewers for their insightful remarks, helpful recommendations, and positive criticism during the review process. Their knowledge and opinions have greatly improved the calibre and objectivity of this work.
- Family and friends: We would like to sincerely thank our family and friends for their unflagging support, patience, and inspiration during this research adventure. Their support and encouragement have been essential in helping us overcome obstacles and maintain our motivation.
- Additional acknowledgements: If any other people, groups, or institutions have made significant contributions to the research effort, we would like to recognise them and thank them for their help.

All of the aforementioned individuals' efforts were crucial to the accomplishment of this study endeavour. However, the authors alone bear responsibility for any inaccuracies, omissions, or restrictions in this publication.

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