

Autonomous Weed Cutter Leveraging ESP32 and Tiny ML

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Abstract— This research delves into the transformation of agriculture through precision techniques and advanced technology. The focus is on an autonomous AI weed cutter, utilising TinyML, the ESP32 camera module, and a proximity sensor to revolutionise weed management. The study introduces a holistic approach by integrating TinyML's advanced computer vision techniques for real-time weed detection and classification. The ESP32 camera captures field images, processed by TinyML algorithms to identify crops and weeds accurately. Augmenting visual perception, a proximity sensor ensures safe navigation, detecting obstacles and maintaining safe distances from crops. This fusion empowers the system to make informed decisions. Field trials confirm exceptional weed detection and removal accuracy. Integration of TinyML-based vision, ESP32 camera tech, and the proximity sensor optimises efficiency, adaptability, and safety.

Economic and environmental analyses highlight benefits: sustainable practices, potential yield increase, and reduced herbicide usage. In conclusion, this research showcases an autonomous AI weed cutter, seamlessly integrating TinyML, ESP32, and a proximity sensor. This technology amalgamation offers precise weed management, boosting efficiency, reducing environmental impact, and promoting sustainability in agriculture—a pivotal stride toward precision farming's future.

Index Terms— Autonomous weed cutter, ESP32, TinyML, weed management, agricultural robotics, labour reduction, herbicide reduction, agriculture innovation, real-time communication, environmental impact, object detection etc.

I. INTRODUCTION

Precision agriculture has ushered in a new era of technology-driven farming practices, aiming to enhance agricultural efficiency while minimizing environmental impact. Weeds, as one of the most persistent challenges faced by farmers, can lead to substantial crop losses if left unaddressed. Conventional weed management methods, often reliant on manual labour and chemical herbicides, come with their own set of limitations, including increased costs and potential ecological harm. In response to these challenges, our research delves into the development of an innovative solution: an autonomous AI weed cutter.

This research centres around the integration of cutting-edge technologies to create an autonomous system that detects and removes weeds while preserving valuable crops. We combine the power of Tiny ML, a widely used computer vision library, with the ESP32 camera module and a proximity sensor. The Tiny ML library empowers the system to process visual information, enabling real-time weed identification and classification. The ESP32 camera module captures images of the agricultural field, while the proximity sensor ensures the system's safe

navigation by detecting obstacles and maintaining a suitable distance from crops.

The core objective of our research is to present a holistic approach to weed management that not only improves accuracy but also reduces the reliance on labour and chemicals. By seamlessly integrating Tiny ML-based computer vision, the ESP32 camera module, and a proximity sensor, our autonomous AI weed cutter holds the potential to revolutionize how weeds are managed in modern agriculture. This paper outlines the system's design, functionality, and performance evaluation, shedding light on the innovative strides made towards more sustainable and efficient farming practices. As precision agriculture continues to evolve, the development of autonomous systems like the one presented here underscores the significance of technology-driven solutions in shaping the future of agriculture.

II. BACKGROUND

Modern agriculture faces challenges in terms of labour shortage, increasing demand for food production, and the need for sustainable practices. Weeding is a crucial aspect of maintaining healthy crops, but it's labour-intensive and time-consuming. Traditional methods involve manual labour or the use of chemical herbicides, which can have negative environmental impacts. As a result, there's a growing interest in developing automated solutions for weed control.

The project's foundation lies in the concept of automation, where tasks traditionally performed by humans are taken over by machines. Automation not only reduces labour costs but also addresses the labour shortage issue faced by the agricultural sector. Additionally, automation can lead to precise and consistent weed control, potentially reducing the need for chemical interventions.

The choice of the ESP32 microcontroller is based on its versatility and capabilities. The ESP32 offers built-in Wi-Fi and Bluetooth connectivity, making it suitable for remote monitoring and control. This is crucial for an autonomous system that needs to communicate its status, receive commands, and potentially send notifications. The ESP32's processing power is also sufficient for running algorithms related to navigation, decision-making, and sensor data processing.

The integration of TinyML into the project introduces computer vision capabilities. TinyML provides a range of tools and functions for image processing, object detection, and classification. By utilizing TinyML, the autonomous system can "see" its surroundings through cameras or other imaging devices. This enables the system to identify plants, differentiate between crops and weeds, and make informed decisions based on visual data.

Object recognition and classification are fundamental to the success of the weed cutter. TinyML allows the system to analyze images in real-time, identify the presence of weeds, and determine their location relative to the desired plants. This information is crucial for the path planning and navigation aspect of the project.

Path planning involves determining the most efficient route for the autonomous weed cutter to navigate through the field. Algorithms need to consider obstacles, plant layouts, and the locations of weeds. The ESP32, equipped with data from sensors and TinyML's analysis, can make real-time decisions about where to move and how to approach each weed for effective cutting.

In conclusion, the autonomous weed cutter project using ESP32 and TinyML addresses multiple challenges in modern agriculture. It aims to automate the labour-intensive task of weeding, increase efficiency, reduce chemical usage, and promote sustainability. By leveraging the capabilities of the ESP32 microcontroller for control and communication, combined with TinyML's computer vision features for weed detection and navigation, the project demonstrates a practical application of technology to enhance agricultural practices.

III. LITERATURE REVIEW

This research paper presents an innovative solution to tackle the complexities of weed management in agriculture using the integration of ESP32 and TinyML technologies. The current practices in weed control often involve labour-intensive processes or the use of herbicides, which can have adverse environmental effects. Existing automated systems face challenges in accurately identifying and distinguishing between crops and weeds, impacting their overall efficiency.

To overcome these challenges, the authors propose an autonomous weed cutter system that leverages the capabilities of ESP32 and TinyML. This integrated approach allows for real-time image capture using the ESP32 camera module and subsequent processing using TinyML's computer vision algorithms. By harnessing the power of these technologies, the system can effectively differentiate between crops and weeds, enabling precise and targeted weed removal.

Unlike conventional methods, this autonomous weed cutter system aims to provide not only efficient weed management but also a sustainable alternative. By minimizing the reliance on manual labour and reducing the need for chemical herbicides, it contributes to environmentally friendly agricultural practices.

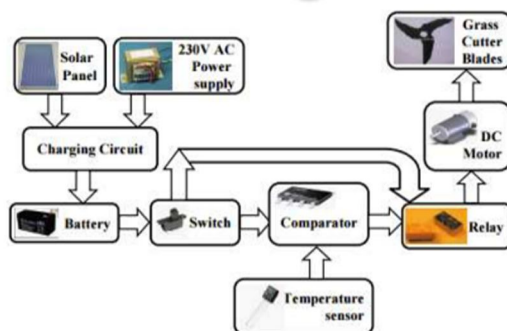
The research paper thoroughly investigates the performance of the proposed system through field trials and experimental setups. The results showcase the system's capability to accurately detect and remove weeds, while the integration of ESP32 and TinyML ensures adaptability and safety.

A. Research on a robotic grass cutter powered by solar energy

The presented research [1] paper introduces an innovative approach to lawn maintenance by utilizing solar-powered technology for grass cutting. The authors highlight the limitations of manually operated grass-cutting devices and propose a novel solution involving the integration of a solar-powered grass-cutter robot. This autonomous system aims to efficiently manage grass-cutting tasks on lawns.

The paper explores the historical evolution of lawnmowers, emphasizing the need for more efficient and automated solutions. It provides insights into the existing landscape of robotic lawnmowers, discussing examples from various manufacturers, including Husqvarna, SN Eno, and Technical Solutions. These examples showcase the advancements in autonomous grass-cutting technology and set the context for the proposed solution.

The identified challenges of traditional grass-cutting methods are discussed, including labour costs, weather dependency, and the need for skilled operators. The authors argue that embracing technology can address these challenges and enhance the overall efficiency of grass-cutting processes.



The methodology section delves into the technical aspects of the solar-powered grass cutter. It explains the key components involved, such as solar panels, batteries, DC motors, solar chargers, and the blade mechanism. These components work in harmony to capture solar energy, store it in batteries through solar charging, and power a DC motor that drives the blade mechanism for efficient grass-cutting.

Autonomous weed cutters outperform solar-driven grass cutters in terms of their ability to accurately target and eliminate weeds, versatile energy sources, adaptability to diverse landscapes, minimized ecological footprint, operational convenience, and potential for learning and enhancement.

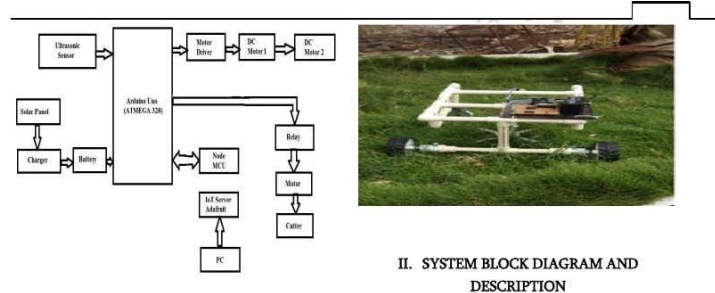
The research paper concludes by highlighting the successful fabrication of the solar-powered grass cutter and its potential implications for lawn maintenance. The authors emphasize the environmental and cost benefits of this technology, suggesting that it could revolutionize the way lawns are maintained while addressing various challenges associated with traditional methods.

B. Automated Grass Cutter Robot Based on IoT

The research paper [2] discusses the development of an automated grass cutter robot for lawn maintenance based on renewable energy sources. The authors emphasize the growing importance of automation in various fields, including agriculture. The paper starts by highlighting the drawbacks of manually operated grass cutters, which contribute to pollution and energy loss due to the use of gas and petrol engines. To address these issues, the authors propose an automated grass cutter system that utilizes a battery as a power source and incorporates technologies like Arduino UNO microcontroller, ultrasonic sensor, and Node MCU for Wi-Fi connectivity. The system aims to provide guidance, obstacle detection, and precise grass-cutting.

The introduction outlines the need for automation in lawn maintenance and the limitations of manual grass cutters. The proposed design is introduced as a solution to improve efficiency, reduce environmental impact, and enhance

uniformity in grass-cutting. The block diagram of the grass cutter robot is provided, showcasing the components' interactions, such as the microcontroller, DC motor, ultrasonic sensor, and Wi-Fi module.



The paper discusses the working principle of the automated grass cutter robot. It explains how the ultrasonic sensor detects obstacles in front of the robot and guides its movement. The DC motor is responsible for the robot's propulsion and blade rotation, ensuring efficient grass-cutting. The authors highlight the importance of safety features when integrating blades into a robotic system.

These studies emphasize the use of renewable energy sources, sensor technologies, and autonomous capabilities to enhance lawn maintenance efficiency while reducing environmental impact.

The conclusion discusses the advantages of the proposed automated grass cutter system, including reduced environmental pollution, minimized human intervention, and efficient grass cutting. The authors suggest that the system could provide an eco-friendly alternative to traditional gas-powered lawnmowers. Additionally, they highlight the potential for further development and improvements in the field of automated lawn maintenance.

Autonomous weed cutters outperform Arduino-driven grass cutters in terms of their ability to accurately target and eliminate weeds, versatile energy sources, adaptability to diverse landscapes, minimized ecological footprint and enhancement.

Overall, the research paper introduces an innovative approach to lawn care through automation and renewable energy sources, focusing on the development of an autonomous grass cutter robot. The paper provides insights into the system's design, operation, and benefits, while also referencing related studies in the field.

The study begins [3] by emphasizing the value of contemporary agricultural practices in a globalized society and the necessity of weed control to increase crop output. Crop yields are reduced as a result of weed competition for resources including water, nutrients, and light. Traditional weed management techniques like hand pulling and herbicide application take time and may be harmful to the environment and human health. The authors suggest creating an autonomous Mow-Bot driven by solar energy that can identify, cut, and remove grass and weeds from farmlands. Additionally, this robot has a security alarm system and a pesticide sprayer to deter intruders.

The Mow-Bot is based on a combination of hardware and software components. It utilizes microcontrollers (Arduino Uno and Raspberry Pi), camera modules (Quantum QHM495LM and ESP32 CAM), sensors (ultrasonic and DHT11), Bluetooth module (HC-05), motor drivers, and motors to function effectively. The Arduino controls motor movements and receives commands from Raspberry Pi and Bluetooth. The Raspberry Pi handles object detection using the YOLO algorithm and TensorFlow framework. The paper outlines how these components interact and collaborate to create an autonomous weed-cutting and grass-trimming robot.

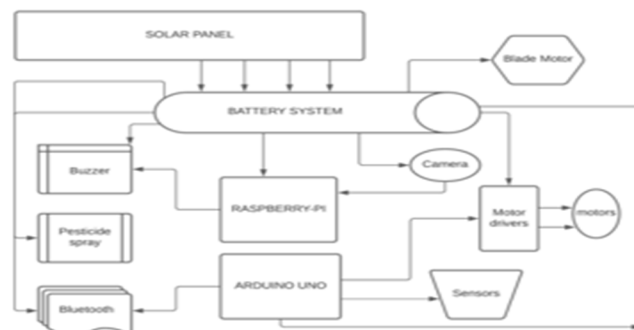


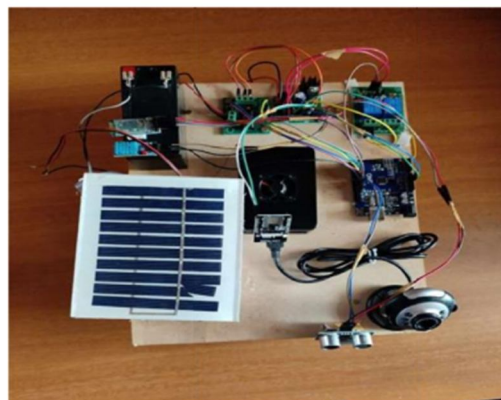
Fig. 1. Block Diagram

The paper describes the technology employed in the project. Computer vision is used for object recognition and analysis. TinyML and TensorFlow are essential tools for image processing, pattern recognition, and object detection. The YOLO (You Only Look Once) algorithm is selected for its real-time object detection capabilities. The Mow-Bot's hardware components are chosen to ensure efficient and accurate operation, including microcontrollers for control, camera modules for vision, sensors for obstacle detection, and motor drivers for precise movement.

The authors provide a visual representation of the Mow-Bot model, detailing how the various components work together. The robot's functionalities are explained, such as its ability to detect and cut grass and weeds, spray pesticides, and provide live security monitoring. The paper presents the results of grass detection using the TensorFlow pre-trained model `ssd_mobilenet_v1_coco`. A dataset of 300 images, including train and test data, is utilized for training. The paper discusses the loss rates during training and the model's performance.



Fig. 3. Results obtained from grass detection model



The paper acknowledges certain limitations, including the efficiency of the solar panel and the charging time of the battery. It suggests potential improvements, such as using advanced camera systems and battery management techniques. Because of the use of Raspberry Pi, its cost increases and it is not affordable for normal farmers and people. The authors propose expanding the model to detect different types of grass and weeds.

In conclusion, the paper introduces the concept of Mow-Bot, an autonomous solar-powered agricultural robot capable of detecting and cutting weeds and grass in farmlands. It outlines the methodology, technology, outcomes, drawbacks, and future scope of the project. The Mow-Bot combines hardware components, software algorithms, and machine learning techniques to address the challenges of weed growth and enhance crop productivity.

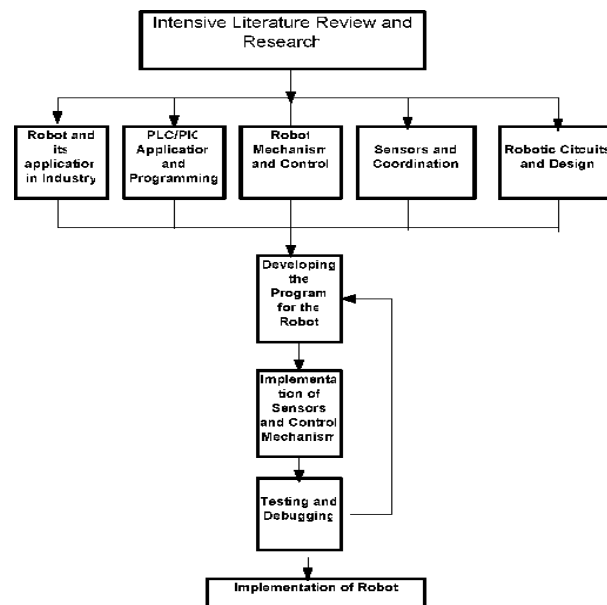
C. Keng-Chih Lin, Shih-Hung Kao, Guo-Shing Huang, and Hsiung-Cheng Lin

The previously mentioned authors researched "Robotic Lawn Mower." The DMA-2450 platform for the ARM9 system was used to develop this energy-efficient robotic lawn mower, which uses the TCM2 posture sensor and a few ultrasonic sensors to give navigational guidance. The secret to compass accuracy, navigation, and control is using the compass to account for the position of a weak magnetic field. This microcomputer processor uses

ultrasound to adjust its trajectory on its own when it encounters impediments, allowing it to avoid them. The energy-saving program and the light circuit breaker will calculate and conserve energy to prevent a power outage.

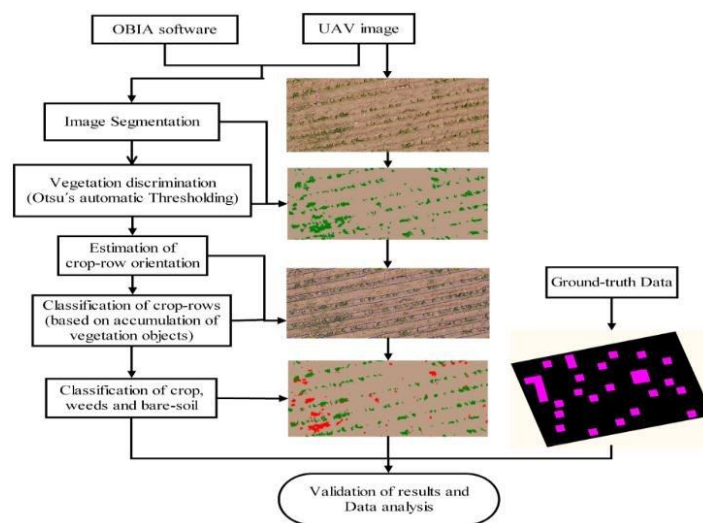
D. Timothee Thien and Taj Mohammad Baloch, respectively.

This group of academics took part in the project "Design and Modeling a Prototype of a Robotic Lawn Mower." This robot was designed to move across a certain amount of flat ground without hitting any obstacles. It was also thought to be fairly inexpensive and simple to install using a PIC microcontroller or PLC controller. Instead of needing to specify every tiny detail, the task in this project was completed by taking a close look at the important design elements that would allow the installed system to autonomously complete its work in a manner that achieved its aims. The mission was completed smoothly and flawlessly thanks to the cooperation of the sensors, microcontroller, and output drivers.



E. Samir Hameed IMI Ami

Hameed and Sarmad Imran Amin researched "Detection of Weed and Wheat Using Image Processing" to discover weeds in wheat crops and prevent their growth to boost wheat growth. using an unmanned aerial vehicle (UAV). Except for the boundaries, which indicate that there were once crops there, the area is entirely uncultivated. Future Convolution Neural Network (CNN) research can make use of better cameras and other sensors to produce better results.



System flow diagram

Image	Weed	Wheat
1	64.69%	35.31%
2	61.45%	38.55%
3	67.30%	32.70%

IV. RESULT

A. Dr. Mythili C and Jerosheja B

They researched a "Solar-Powered Automated MultiTasking Agricultural Robot." Create an automated multi-tasking vehicle for the agricultural industry that may improve productivity and accuracy while reducing weed and insect infestations in the field and requiring less frequent vehicle recharging. The robot is controlled by a Raspberry Pi 3 Model B, which in turn is controlled by four DC gear motors (12V). The operations involved in seeing the field's status, sensor data, and presenting live video from the field are all being controlled and monitored by an application that is currently being developed.

B. Reddy Sudhee and Bandi Narasimha Rao

They thus created a "Surveillance Camera with IoT and Raspberry Pi." This investigation and the use of Raspberry PiIoT recommended a security camera. The pi-cam camera will be used to take the photos. Since the suggested surveillance system only records video and snaps images when motion is detected in the monitored area, it uses less storage space. A PIR sensor can be used to detect movement. Implementing the suggested security camera is straightforward; after receiving the data, the receiver decodes it. being encrypted at the transmitter. The suggested approach enables secure data transmission as a result. It can be improved to pinpoint the individual's precise position. The suggested method saves a significant amount of memory because it only takes pictures and records video when motion is detected. It is not utilized for recording; only for live streaming. The video doesn't play nonstop.

C. N. Aggarwal, Y. Kalra, P. Jain, M. Sehgal, M. Jain, and

The creators of the paper created a four-wheeled mobile robot with object detection and gesture control. In this paper, the development of a mobile robot with four wheels and a gesture-controlled robot arm manipulator system is described. The human hand is used to control the arm's motion using an accelerometer and a Wi-Fi-based gesture control mechanism. An Arduino, relay motor drivers, a camera, wheels, PCB casting, and ultrasonic sensors are a few of the components used. The approach still provides a way to completely discriminate between objects. There ought to be a supervisor or director present at all times (lacks autonomy)

Dipak Wadavane, Kumawat Mukesh, and Naik AnkitThe researchers behind this project created a "solar-powered sprayer for agricultural use." Sprayers are mechanical devices made to make the process of dispensing liquids quick and easy. They come in a variety of sizes and forms. One of the better substitutes for the petrol-powered pesticide sprayer pump is the solar-powered pesticide sprayer pump. A solar panel, a motor pump, a pesticide, a nozzle, a battery, and a relay were a few of the components employed. However, there is room for improvement in battery management. To avoid damaging the battery's cells, extra energy should be utilised elsewhere rather than being stored in the battery.

V. OBJECTIVES

- 1) Automated weed control
- 2) Weed Detection and classification
- 3) Real -Time Decision Making
- 4) Minimized chemical usage
- 5) Increased Crop yield
- 6) Promotion of sustainable agriculture

VI. METHODOLOGY

Designing an autonomous weed cutter using ESP32 and TinyML involves several steps, from hardware setup to software development. Here's a detailed methodology:

A. Define Requirements and Goals

Clearly outline the project's objectives, such as weed detection accuracy, navigation precision, and system reliability.

Identify the types of weeds to be targeted, the size of the agricultural area, and any specific environmental conditions.

B. Hardware Setup

Assemble the hardware components, including the ESP32 microcontroller, motors for propulsion, cutting mechanism (e.g., rotary blades), cameras for capturing images, and any additional sensors for obstacle avoidance or terrain analysis.

C. Sensor Integration

Configure the cameras and other sensors to capture images and relevant data from the field.

Set up any distance or obstacle sensors to ensure the system can navigate safely and efficiently.

D. ESP32 Programming

Program the ESP32 to control the motors, read sensor data, and manage communication with other components.

Establish Wi-Fi or Bluetooth connectivity to enable remote monitoring and control.

E. TinyML Integration

Set up TinyML on the ESP32 by installing the necessary libraries and dependencies.

Configure the cameras to capture images and integrate TinyML functions for image processing.

F. Image Preprocessing

Capture images of the field using the cameras.

Apply preprocessing techniques like resizing, noise reduction, and image enhancement to improve the quality of the captured images.

G. Weed Detection Algorithm

Develop an algorithm using TinyML to identify weeds within the images.

This could involve colour-based segmentation, edge detection, contour analysis, or machine learning techniques if a dataset is available.

H. Weed Classification (Optional)

If necessary, implement a classification algorithm to differentiate between various types of weeds and crops.

Machine learning models like convolutional neural networks (CNNs) can be trained for this purpose.

I. Real-time Decision Making

Implement decision-making logic that uses the data from TinyML and sensors to adjust the path and cutting strategy in real time.

Ensure that the system can adapt to changes in the field environment.

J. Cutting Mechanism Control

Program the ESP32 to control the cutting mechanism based on the detected weeds' positions.

Coordinate the cutting action with the movement of the weed cutter to ensure precise cutting

K. Testing and Refinement

Test the autonomous weed cutter in controlled environments to validate its weed detection accuracy, navigation efficiency, and cutting effectiveness.

Iterate on the algorithms and parameters based on testing results to improve performance.

L. Field Testing

Conduct real-world field tests to assess the system's performance in varying conditions.

Collect data and analyze the results to identify any areas for further improvement

M. Documentation and Presentation

Document the entire development process, including hardware schematics, software code, algorithms, and testing outcomes.

Create a comprehensive presentation or report detailing the project's methodology, challenges, and achievements. Developing an autonomous weed cutter requires a multidisciplinary approach, combining skills in robotics, programming, computer vision, and agriculture. Regular testing, refinement, and collaboration between team members are essential for successfully creating a functional and efficient system.

VII. CONCLUSION

To conclude, the autonomous weed cutter developed using ESP32 and TinyML is a breakthrough in precision agriculture. This research contributes to the ongoing conversation on sustainable agricultural practices by addressing critical issues such as labour shortages, chemical contamination, and resource optimization. The autonomous weed cutter is a groundbreaking example of how technology can be used to overcome long-standing agricultural challenges by combining ESP32's computational power and TinyML's advanced image-processing capabilities. This promotes increased productivity while also promoting environmental responsibility. The following sections of this paper will go into greater detail on the methodology, experimentation, and findings that support the transformative potential of this innovative solution in modern agriculture

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