

AI BASED ROBOTIC SYSTEM FOR THE POLLINATION OF VEGETABLES

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Abstract - Pollination plays a crucial role in agricultural productivity, especially in vegetable crops such as tomato, cucumber, and brinjal. However, the decline in natural pollinators due to climate change, pesticide use, and habitat loss has created a need for alternative pollination methods. This paper presents an AI-based robotic system designed for automated pollination of vegetable crops. The system utilizes computer vision techniques, specifically the YOLO algorithm, to detect flowers and classify their maturity stages. A dataset consisting of bud, anther, and post-anther stages of tomato flowers is used to train the model. Pollination is selectively performed only during the anther stage to ensure effective fertilization. The system integrates a Raspberry Pi for image processing, an Arduino Nano for control, and a robotic mechanism for precise pollen spraying. Environmental parameters such as temperature and humidity are monitored to optimize pollination conditions. Experimental results demonstrate that the proposed system improves pollination accuracy, reduces manual labor, and enhances crop yield, making it a promising solution for smart agriculture.

Key Words: Raspberry Pi, Arduino Nano, Temperature and Humidity sensor,

1. INTRODUCTION

Agriculture plays a vital role in ensuring food security and economic stability across the globe. Among various agricultural processes, pollination is essential for the reproduction of flowering plants and directly affects crop yield and quality. Vegetable crops such as tomatoes depend heavily on proper pollination for fruit formation. Traditionally, pollination is carried out by natural agents like bees, butterflies, and other insects. However, the global population of natural pollinators has been declining at an alarming rate due to factors such as climate change, environmental pollution, excessive pesticide use, and habitat loss

This decline has led to reduced crop productivity and increased dependence on manual pollination methods. Manual pollination, although effective, is labor-intensive, time-consuming, and not suitable for large-scale farming. With advancements in artificial intelligence and robotics, there is a growing opportunity to develop automated solutions for agricultural applications. Computer vision techniques enable machines to analyze plant conditions, while robotic systems can perform precise actions. In this context, the proposed system introduces an AI-based robotic solution capable of detecting flowers, identifying their maturity stage, and performing selective pollination. The integration of AI, embedded systems, and automation in agriculture not only enhances efficiency but also supports sustainable farming practices. This project aims to address the limitations of traditional pollination methods by providing an intelligent, scalable, and cost-effective solution.

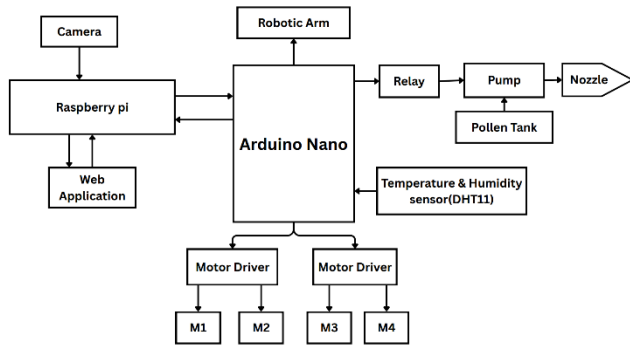
2. WORKING PRINCIPLE

The proposed system operates using computer vision and embedded control to perform automated pollination. A camera captures real-time images of plants, which are processed by the Raspberry Pi using a trained YOLO model to detect flowers and classify their maturity stages as bud, anther, or post-anther. Based on this classification, the system performs pollination only when the flower is in the anther stage, which is suitable for fertilization. The Raspberry Pi sends control signals to the Arduino Nano, which actuates the robotic arm and activates the pump mechanism. The pollen solution is then sprayed through a fine nozzle onto the target flower. If the flower is not in the correct stage, the system skips it and moves to the next, ensuring efficient and selective pollination.

BLOCK DIAGRAM

The block diagram represents the overall architecture of the AI-based robotic pollination system. The system uses a camera to capture images, which are processed by the Raspberry Pi using the YOLO algorithm to detect flowers.

Based on the result, the Arduino Nano controls the robotic arm and spray mechanism. When a suitable flower is detected, the pump sprays pollen solution through a nozzle. Sensors monitor temperature and humidity, and all



components are powered by a common supply

3.1 Arduino Nano

The Arduino Nano is a miniature microcontroller board. It uses the ATmega328P chip, similar to the Uno. Its compact size makes it perfect for projects with limited space. You can program it via USB. It has both digital and analogue input/output pins. Hobbyists and professionals use it for diverse electronic applications. Newer versions add features like Wi-Fi and Bluetooth.



Fig 3.1 Arduino Nano

3.2 Raspberry Pi

The Raspberry Pi is a tiny, single-board computer. It's designed to be affordable and versatile. It runs on Linux based operating systems. It has a processor, RAM, and various ports. You can connect it to a monitor, keyboard and mouse. It's used for education, hobby projects, and industrial applications. It has GPIO pins for connecting electronic components. It's popular for robotics, media centres and home automation. A large community provides support and resources.



Fig 3.2 Raspberry Pi

3.3 Endoscopic Camera

The camera is used to capture real-time images of the plants and flowers in the field. These images are essential for detecting and classifying the flower stages. It continuously streams visual data to the Raspberry Pi for processing. The quality of images directly affects the accuracy of detection. It enables the system to operate dynamically in real-time conditions. The camera is a



crucial input device for the computer vision system.

Fig 3.3 Endoscopic Camera

3.4 Servo Motor

A Servo motors are used to control the movement of the robotic arm in precise directions. They provide accurate angular positioning required for targeting the flowers. These motors help in aligning the nozzle with the detected flower. They operate based on signals received from the Arduino Nano. The use of servo motors ensures smooth and controlled motion. This improves the accuracy of the pollination process.



Fig 3.4 Servo Motor

3.5 Motor Driver

A The motor driver is responsible for controlling the speed and direction of DC motors used in the system. It acts as an interface between the Arduino Nano and the motors, allowing safe operation. Since motors require higher current than the controller can supply, the motor driver amplifies the signals. It enables forward, backward, and directional movement of the robotic platform. The driver also ensures smooth operation and prevents damage to electronic components. It plays a vital role in mobility and motion control. Proper motor driving enhances system stability and performance.

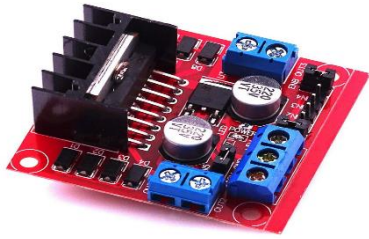


Fig 3.5 Motor Driver

3.6 Relay Module

The relay module acts as a switching device that allows low-power signals to control high-power components like the pump. It operates by opening or closing the circuit based on signals from the Arduino Nano. When activated, it turns ON the pump to initiate spraying of the pollen solution. When deactivated, it stops the spraying process. The relay provides electrical isolation between control and power circuits, ensuring safety. It also improves system reliability by preventing overload conditions. The use of a relay simplifies the control of high-voltage components. It is crucial for the efficient functioning of the spraying mechanism. relay module acts as an electrically operated switch that allows low-power control signals to manage high-power devices such as the pump. It provides isolation between the control circuit (Arduino Nano) and the power circuit, ensuring safety and reliability. When the Arduino sends a signal to the relay, it activates the switch, allowing current to flow and turning the pump ON.



Fig 3.6 Relay Module

3.7 DHT11

The temperature and humidity sensor is used to monitor environmental conditions that directly influence the pollination process. It continuously measures ambient temperature and relative humidity and provides this data to the control system. These environmental factors play a crucial role in determining pollen viability and fertilization success. For tomato flowers, optimal pollination conditions typically range between 20–27°C temperature and 60–70% humidity

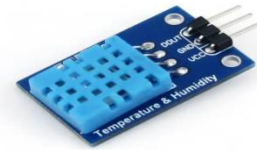


Fig 3.7 DHT11

3.8 Pump and Nozzle

The pump and nozzle assembly is responsible for delivering the pollen solution onto the flower in a controlled manner. The pump draws the solution from the storage tank and forces it through the nozzle under pressure. The nozzle is designed to produce a fine mist spray, which ensures uniform distribution of pollen particles. A carefully selected nozzle size allows precise application without excessive wastage. The spraying action mimics natural pollination mechanisms such as wind or insect activity.



Fig 3.8 Pump and Nozzle

3.9 Power Supply

The power supply unit provides the necessary electrical energy required for the operation of all system components. It ensures stable and regulated voltage levels for devices such as Raspberry Pi, Arduino Nano, sensors, and motors. Since different components operate at different voltage levels, the power supply system includes regulation and distribution mechanisms. A reliable power source is essential to maintain continuous operation and prevent system failure. It also protects components from voltage fluctuations and electrical noise. Proper power management improves system efficiency and longevity. The power supply acts as the backbone that supports the entire system's functionality

3.10 Pollen Tank

The pollen tank is used to store the prepared pollen solution required for artificial pollination. It acts as a reservoir that supplies the solution to the pump during operation. The tank is designed to maintain the quality and consistency of the solution by preventing contamination, evaporation.

4 CIRCUIT DIAGRAM

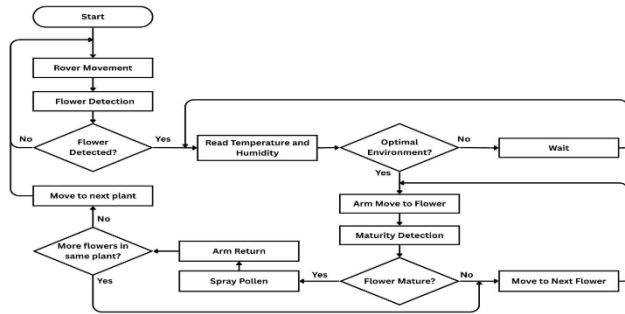


Fig 4.1 Circuit Diagram for Pollination System

5 RESULT AND DISCUSSIONS

The The proposed AI-based robotic pollination system was tested using tomato plants to evaluate its performance under controlled conditions. A dataset consisting of three distinct stages of tomato flower development—bud, anther, and post-anther—was used to train and validate the YOLO-based detection model. The system demonstrated high accuracy in classifying flower stages and identifying the appropriate stage for pollination. The results show that the system effectively performs selective pollination by activating the spraying mechanism only when the flower is in the anther stage. This selective approach ensures that pollination occurs only during the biologically suitable phase, thereby improving fertilization efficiency. Flowers in the bud and post-anther stages were correctly identified and skipped, reducing unnecessary pollen usage. The robotic arm mechanism provided precise positioning of the nozzle, enabling accurate targeting of flowers. The controlled spray mechanism ensured uniform distribution of pollen solution, enhancing pollination effectiveness. The integration of environmental sensing allowed the system to operate under optimal temperature and humidity conditions, further improving performance. Overall, the system achieved reliable detection, efficient decision-making, and precise pollination. The results indicate a significant reduction in manual labor and pollen wastage, along with potential improvements in crop yield and quality. The discussion highlights that the system is scalable and can be adapted for other crops with appropriate training.

6 CONCLUSION

In proposed AI-based robotic pollination system presents an innovative and efficient solution to address the challenges associated with declining natural pollinators and manual pollination methods. By integrating computer

vision, robotics, and environmental sensing, the system enables accurate detection, intelligent decision-making, and precise pollination. The experimental results demonstrate its effectiveness in improving pollination efficiency, reducing labor requirements, and enhancing agricultural productivity. This system represents a significant advancement toward the adoption of smart and sustainable agricultural technologies.

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