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Eco Vision: Intelligent Quadruped Agricultural Robot for Plant Monitoring and Automated Irrigation

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A B S T R A C T

Agriculture plays an important role in food production and economic development, but traditional plant monitoring, irrigation, and disease identification require continuous human effort. This paper presents Eco Vision, an intelligent quadruped agricultural robot developed using Raspberry Pi 3B+. The system combines a camera for plant detection, servo-driven legs for movement, and a servo-operated arm carrying a soil-moisture sensor. The moisture reading is processed by the Raspberry Pi and compared with a predefined threshold. When the soil is dry, a water pump is activated to supply water to the plant; watering is skipped when sufficient moisture is present. The camera can also be used for image-based observation of visible plant conditions, while plant and moisture information can be communicated to a mobile application. By integrating mobility, sensing, computer vision, and controlled irrigation, Eco Vision aims to reduce manual effort and unnecessary water use and support smart and sustainable agriculture.

Keywords: Eco Vision, Quadruped Agricultural Robot, Raspberry Pi 3B+, Plant Detection, Soil Moisture Monitoring, Automatic Irrigation, Computer Vision, Smart Agriculture

INTRODUCTION

The growing use of technology in agriculture has created opportunities to improve crop monitoring, irrigation, and plant-health assessment. Traditional farming methods often require farmers to inspect plants manually, check soil moisture, provide water, and identify visible signs of disease. These activities consume time and labour, and irregular monitoring can lead to water wastage or delayed action. Internet of Things (IoT), robotics, artificial intelligence, and computer vision offer methods for improving agricultural productivity and reducing repetitive manual work. Eco Vision is proposed as an intelligent quadruped agricultural robot using Raspberry Pi 3B+ to approach plants, detect plant pots using a camera, measure soil moisture with a sensor mounted on a robotic arm, and activate a water pump when watering is required. The camera also supports observation of visible plant conditions, and monitoring information can be sent to a mobile application. The proposed platform brings movement, sensing, and targeted irrigation together in a single system for smart plant care.

LITERATURE SURVEY

1. IoT Based Monitoring System in Smart Agriculture

Authors: S. R. Prathibha, A. Hongal, and M. P. Jyothi

Journal: International Conference on Recent Advances in Electronics and Communication Technology

Year: 2017

Summary: This paper presents an IoT-based smart agriculture system designed to monitor environmental parameters such as soil moisture, temperature, and humidity. It demonstrates how sensor-based monitoring can provide information about field conditions and support improved agricultural management.

2. IoT Based Smart Crop-Field Monitoring and Automation Irrigation System

Authors: R. Nageswara Rao and B. Sridhar

Journal: Proceedings of the Second International Conference on Inventive Systems and Control (ICISC)

Year: 2018

Summary: This research focuses on automated irrigation using soil-moisture sensors. The system monitors soil conditions and supports the automatic supply of water, helping reduce the need for continuous manual irrigation.

3. Deep Learning in Agriculture: A Survey

Authors: J. Kamilaris and F. X. Prenafeta-Boldú

Journal: Computers and Electronics in Agriculture, Vol. 147, pp. 70–90

Year: 2018

Summary: This survey explains the applications of deep learning and computer-vision techniques in agriculture. It discusses plant disease detection, crop monitoring, and autonomous agricultural robots, and describes how image processing and artificial intelligence can improve the accuracy and efficiency of smart farming systems.

4. DeepFruits: A Fruit Detection System Using Deep Neural Networks

Authors: A. Sa, P. Ge, F. Dayoub, B. Upcroft, T. Perez, and C. McCool

Journal: Sensors, Vol. 16, No. 8

Year: 2016

Summary: The authors developed a deep-learning-based vision system for detecting fruits in agricultural environments using camera sensors and neural networks. The work demonstrates how computer vision can be integrated with robotic systems for agricultural monitoring and automated farming applications.

5. Wireless Sensor Networks for Agriculture: The State-of-the-Art in Practice and Future Challenges

Authors: T. Ojha, S. Misra, and N. S. Raghuwanshi

Journal: Computers and Electronics in Agriculture, Vol. 118, pp. 66–84

Year: 2015

Summary: This paper reviews wireless sensor networks in precision agriculture for monitoring soil moisture, crop health, and environmental conditions. It highlights the benefits of sensor-based automation and remote monitoring, while discussing challenges associated with agricultural sensor-network deployment.

METHODOLOGY

The proposed Eco Vision methodology integrates computer vision, quadruped locomotion, soil-moisture sensing, and automatic irrigation. A Raspberry Pi 3B+ functions as the central controller and communicates with the USB camera, PCA9685 servo driver, servo motors, soil-moisture sensor, and water pump. The process is divided into the following stages: image capture, plant selection, movement, moisture measurement, irrigation decision, and user notification.

1. Image Acquisition and Plant Detection

A USB camera connected to the Raspberry Pi captures images of the surrounding area. Python and OpenCV are used to process the images and identify a visible plant or plant pot. The detected position is treated as the target for the robot. Detection quality may depend on lighting, camera angle, and background conditions.

2. Movement and Positioning

The Raspberry Pi sends control signals to the servo motors through the PCA9685 driver. Coordinated operation of the four legs enables the robot to move toward the selected plant. Once positioned near the plant, the servo-operated arm is lowered toward the soil for moisture measurement.

3. Soil Moisture Monitoring

A soil-moisture sensor fitted to the end of the robotic arm is placed in the soil to obtain a moisture reading. The Raspberry Pi reads the sensor output and compares it with a predefined threshold. The threshold should be calibrated for the soil type and plant requirements before regular operation.

4. Automatic Watering

If the measured moisture level is below the selected threshold, the Raspberry Pi activates the relay to switch ON the water pump and deliver water to the plant. The pump is switched OFF after the required watering interval. If the soil moisture is sufficient, the controller skips irrigation.

5. Plant Health Monitoring

The camera can also capture images of visible plant conditions. Image-processing methods may be used to highlight symptoms such as leaf dryness or visibly affected areas. These observations can be stored or shared with the user; reliable disease classification would require additional image data and model validation.

6. User Notification and Repetition

Plant-condition observations and soil-moisture readings can be communicated to the user through a mobile application or other interface, where connectivity is available. After completing one plant's monitoring cycle, the robot can select another detected plant and repeat the process.

7. Testing and Validation

The prototype can be evaluated by testing plant-pot detection, leg movement, arm positioning, sensor readings, and pump operation. Moisture readings should be compared with a reference measurement to assess sensor consistency, while the pump response should be checked against the selected threshold. Repeated trials can be used to assess movement stability, positioning accuracy, and the repeatability of the complete monitoring cycle.

Program Flow

1. Start Program

The system starts when power is supplied to the Raspberry Pi and the connected hardware. The controller begins execution of the Eco Vision program.

2. Initialize Hardware Modules

The Raspberry Pi initializes the USB camera, PCA9685 servo driver, servo-control channels, soil-moisture sensor interface, and water-pump control.

The connected modules are placed in their initial operating states.

3. Image Acquisition

The USB camera captures images of the surrounding area for plant and plant-pot detection.

4. Plant Detection and Target Selection

Python and OpenCV process the captured image to identify a plant or pot and determine the target position.

The detected plant is selected for the next monitoring operation.

5. Robot Movement

The Raspberry Pi sends control signals through the PCA9685 driver to coordinate the servo-driven legs.

The quadruped moves toward the selected plant and positions itself for sensing.

6. Robotic Arm Positioning

The servo-controlled arm moves the soil-moisture sensor toward the plant's soil.

The sensor is inserted into the soil to obtain a moisture reading.

7. Moisture Measurement and Decision

The Raspberry Pi reads the soil-moisture value and compares it with a predefined threshold.

If the soil is dry, the system proceeds to watering; otherwise, watering is skipped.

8. Automatic Watering

When watering is required, the Raspberry Pi switches ON the water pump to supply water to the plant.

After the controlled watering operation, the pump is switched OFF.

9. Plant Health Monitoring and Notification

The camera observes visible plant conditions, and plant-status and moisture information can be communicated to the user through a mobile application.

BLOCK DIAGRAM

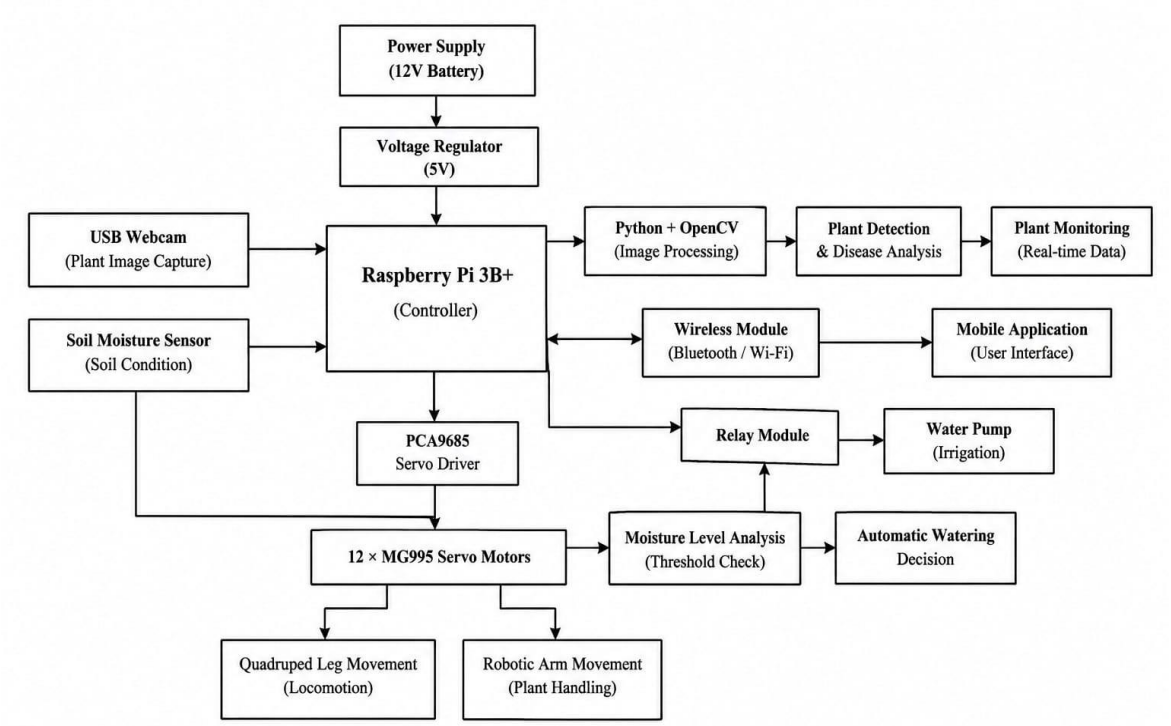


Fig. 1 Block Diagram of Eco Vision – Intelligent Quadruped Agricultural Robot

COMPONENTS USED

Hardware Components

1. Raspberry Pi 3B+ – Acts as the main controller and processes camera images and sensor readings.
2. USB Camera – Captures images for plant and plant-pot detection and observation of visible plant conditions.
3. PCA9685 16-Channel Servo Driver – Controls the servo motors used for leg movement and robotic-arm positioning.
4. MG995 Servo Motors – Provide movement for the quadruped legs and robotic arm.
5. MG90S Servo Motors – Provide additional servo actuation in the proposed mechanism.
6. Capacitive Soil-Moisture Sensor – Measures the moisture level of the soil.
7. Water Pump and Two-Channel Relay – Control the supply of water to the plant.
8. Battery and Power-Management Components – Supply and regulate power for the robot and its electronics.
9. Mechanical Frame, Wiring and Connectors – Support the four-leg structure and provide electrical connections.

Software Components

1. Raspberry Pi OS and Python – Provide the software environment for system control and processing.
2. OpenCV – Processes camera images for plant and pot detection and visible plant-condition analysis.

ADVANTAGES:

1. Combines plant detection, soil-moisture monitoring, and automatic irrigation in one mobile agricultural platform.

2. Quadruped locomotion is intended to help the robot approach plants rather than relying only on fixed sensing points.

3. Soil-moisture-based watering helps avoid supplying water when the soil already contains sufficient moisture.

4. Camera-based plant detection helps identify the target plant for monitoring.

5. The robotic arm positions the moisture sensor near the plant's soil for direct measurement.

6. Plant-condition and moisture information can be communicated to a mobile application for user monitoring.

7. The system aims to reduce repetitive manual monitoring, irrigation effort, and unnecessary water use.

8. The modular combination of Raspberry Pi, servo driver, sensors, camera, and pump allows further development.

9. The design provides a platform for future integration of advanced AI, navigation, and environmental sensors.

LIMITATIONS:

1. The current proposal uses a camera-based detection process and depends on suitable image capture and processing.

2. Quadruped movement and positioning require coordinated control of multiple servo motors.

3. Soil-moisture readings depend on correct sensor placement and contact with the soil.

4. The watering decision depends on the predefined moisture threshold being selected appropriately.

5. The present system description does not specify GPS-based navigation for large agricultural fields.

6. Advanced AI-based disease prediction is identified as a future enhancement rather than a fully described current feature.

7. Cloud-based monitoring and data storage are proposed as future extensions.

8. Temperature, humidity, and gas sensing are not included in the current component list.

9. Automatic weed removal is described as a possible future addition and is not part of the current system workflow.

10. Field-scale operation and long-duration performance require further development and testing.

11. Battery capacity may limit operating time, especially when several servo motors and the water pump run during the same cycle.

12. Uneven, muddy, or wet ground may affect the robot's balance and movement; the leg mechanism requires further testing under different field conditions.

13. Camera performance may decrease in poor lighting or when plants are partly hidden, so detection accuracy should be tested in realistic environments.

14. The soil-moisture sensor may require periodic calibration and cleaning to maintain consistent readings over repeated use.

RESULT:

The Eco Vision proposal defines a quadruped agricultural robot that integrates plant detection, soil-moisture measurement, and automatic watering using a Raspberry Pi 3B+. The described workflow captures images with a USB camera, identifies a plant or pot using Python and OpenCV, and moves the robot toward the selected target using servo-driven legs controlled through the PCA9685 driver. A sensor mounted on the robotic arm measures soil moisture, and the Raspberry Pi activates the water pump when the soil is dry. When sufficient moisture is detected, watering is skipped. The design also provides for communicating plant and moisture information to a mobile application. These are the intended functions of the proposed system; measured prototype performance and experimental results are not provided in the supplied project document.

CONCLUSION AND FUTURE SCOPE

Conclusion:

Eco Vision presents an intelligent approach to plant monitoring and care by combining computer vision, soil-moisture sensing, quadruped movement, and automated irrigation using a Raspberry Pi 3B+. The camera is used to identify plants and plant pots, while the mobile quadruped platform approaches the selected plant. A robotic arm positions the soil-moisture sensor in the soil, and the controller activates the water pump when the measured moisture level indicates that watering is required. The system is intended to reduce unnecessary water use and manual effort in plant monitoring and irrigation. The integration of image processing and sensor-based control provides a foundation for further development of smart and sustainable agricultural applications.

Future enhancements:

1. Advanced AI and deep-learning models can be integrated for more accurate plant-disease prediction.

2. A robotic cutter or spraying mechanism can be added for automatic weed removal.

3. GPS modules can be integrated to support autonomous navigation in large agricultural fields.

4. Solar panels can be added to power the robot and improve energy efficiency.

5. Cloud platforms can be used for remote monitoring and storage of plant-condition data.

6. Voice-assistant and mobile-application controls can be added for remote operation.

7. Temperature, humidity, and gas sensors can be integrated for wider environmental monitoring.

8. The plant-detection and movement process can be improved for more reliable operation across different field conditions.

9. The robotic system can be extended with additional sensing and actuation modules for precision agriculture.

10. Further prototype testing can be carried out to evaluate navigation, sensing accuracy, irrigation control, and long-term operation.

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