IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, May 2026
Impact Factor: 8.2

Smart Prunning Machine with Height Sensing for Pigeon Pea Farming

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Abstract: *Agriculture is an important sector in India, where pruning plays a key role in improving crop growth and yield. In pigeon pea farming, proper pruning helps in improving branching, enhancing sunlight penetration and increasing yield. However, traditional pruning methods are primarily manual, which makes them labor-intensive, time-consuming and often inconsistent in terms of cutting height and quality. the design and development of a Smart Pruning Machine with Height Sensing specifically for pigeon pea farming. The proposed system integrates sensor-based technology with automated control mechanisms to detect plant height and perform uniform cutting at a predefined level. The machine consists of sensors for plant detection, a height sensing module, a microcontroller-based control unit and a motor-driven cutting mechanism. Once a plant is detected, the system measures its height and adjusts the cutter accordingly to ensure precise and consistent pruning. the implementation of automation in pruning not only reduces human effort but also improves efficiency and accuracy.*

Keywords: Agriculture, Automation, Embedded system, Height sensing, Pigeon pea, Pruning machine

I. INTRODUCTION

Agriculture remains a vital sector in India, with crops like pigeon pea (*Cajanus cajan*) playing a significant role in food security and soil health. Effective crop management practices, particularly pruning, are essential for enhancing plant growth, improving yield and ensuring better resource utilization. However, traditional pruning methods are manual, time-consuming and often lack precision.

With the advancement of automation and embedded systems, smart agricultural solutions are emerging to address these challenges. This paper presents a Smart Pruning Machine with Height Sensing, designed to automate the pruning process by

accurately detecting plant height and performing uniform cutting. The system aims to reduce labour dependency, improve operational safety and enhance crop productivity. By integrating sensor-based technology into farming practices, the proposed solution contributes to the development of efficient and sustainable precision agriculture.

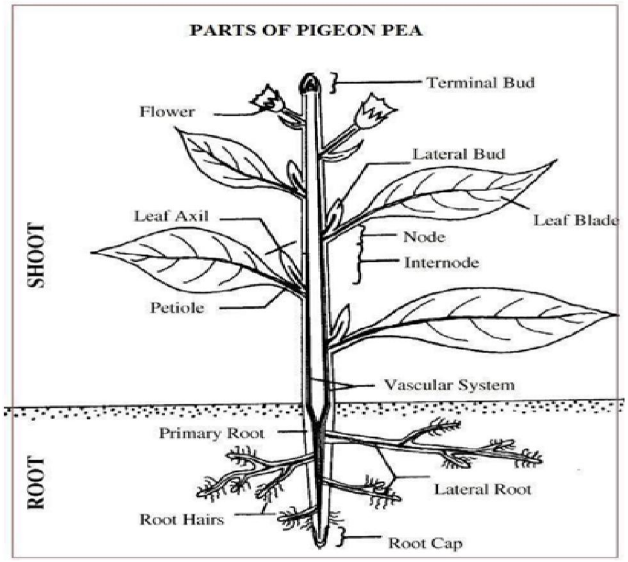

Fig 1 Parts Of Pigeon Pea Plant

In recent years, the integration of automation and intelligent systems in agriculture has gained significant attention due to the increasing demand for higher productivity and reduced manual labour. Traditional farming practices, while effective, often lack precision and consistency, especially in operations like pruning. This has led to the development of smart agricultural machines that can perform tasks with improved accuracy, efficiency and reliability. In order to perform pruning more effectively, it is important to understand the basic anatomy of the pigeon pea plant. The provided diagram (Parts of Pigeon Pea) shows the detailed structure of the plant, which is divided into two main sections:

- Shoot System (Above the soil)
- Root System (Below the soil)

Each part of the shoot and root plays an important role in plant growth and health and proper pruning focuses mainly on the shoot part.

1 Shoot System (Above Ground Part)

The shoot system consists of structures such as the terminal bud, lateral buds, nodes, internodes, leaves, flowers and vascular system. These parts are essential for capturing sunlight, producing food through photosynthesis and growing vertically.

Terminal Bud :- Located at the top of the plant, this bud is responsible for vertical growth. Pruning involves cutting above this area to limit height and promote branching. By removing the terminal bud at the right stage, the plant diverts its energy into developing more lateral branches, which increases flower and pod count.

Lateral Bud :- These buds are located along the sides of the stem. After pruning, these buds grow into new branches, helping the plant develop more flowering points.

Node and Internode :- A node is the point where leaves and buds originate. The section between two nodes is known as an internode. Pigeon pea plants pruned at a specific node level show better uniformity in branch development.

Leaf Blade and Petiole :- The leaf blade performs photosynthesis, whereas the petiole holds the leaf to the stem. Healthy leaves are crucial for energy production, which supports new branch formation after pruning. Understanding these shoot components helps define the exact height and position where pruning should occur. If pruning is done too low, the plant may lose energy if too high, the desired branching may not be achieved.

2 Root System (Below Ground Part)

The root system includes the primary root, lateral roots, root hairs, root cap and the vascular system that connects roots to the stem.

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Primary Root & Lateral Roots :- The primary root is the main root that grows downward and firmly anchors the plant in the soil. It plays an essential role in absorbing water and minerals from the deeper layers of the ground. From this primary root, several lateral roots emerge and spread outward through the topsoil.

II. LITERATURE REVIEW

A literature survey provides an overview of the existing research and technological developments related to a particular field of study. For this project, it focuses on identifying previous work done on pruning systems, height-sensing technologies and automation in agriculture, especially for pigeon pea cultivation.

Zheng Y. (2024) conducted an in-depth study on the calibration of ultrasonic sensors, emphasizing its importance in achieving accurate and reliable canopy height measurements in agricultural applications. Ultrasonic sensors operate by emitting sound waves and measuring the time taken for the echo to return after hitting an object, such as crop foliage. However, the accuracy of these measurements is highly sensitive to environmental conditions. Zheng's methodology involved a systematic calibration process under controlled laboratory and semi-field conditions, where variables such as temperature, wind speed, humidity, and plant density were carefully monitored and adjusted. The study established calibration curves and compensation techniques to minimize measurement errors caused by these external factors. Special attention was given to signal reflection variability due to different crop structures, ensuring that the sensors could consistently detect plant height across varying canopy densities. Through repeated experimentation and validation, the research demonstrated that proper calibration significantly enhances sensor precision and repeatability, making them reliable for real-time agricultural monitoring systems. One of the major advantages highlighted in the study is the cost-effectiveness of ultrasonic sensors compared to advanced technologies like LiDAR and machine vision systems. Ultrasonic sensors are relatively inexpensive, easy to install, and consume less power, making them highly suitable for integration into automated agricultural machines such as smart pruning systems or crop monitoring devices.

Wu J. (2023) presented a detailed study on boom height detection by developing an automated feedback loop system that integrates ultrasonic sensing with actuator-based control mechanisms. In this approach, ultrasonic sensors are mounted on agricultural machinery specifically boom sprayers to continuously measure the distance between the boom and the ground or crop canopy. These sensors emit ultrasonic waves and calculate the return time of the reflected signal to determine height in real time. The collected data is then fed into a control unit, which processes the measurements and compares them with a predefined optimal height. If any deviation is detected due to uneven terrain, crop variation, or machine movement, the system automatically triggers actuators to adjust the boom position accordingly. This closed-loop control system ensures that the boom maintains a consistent height throughout operation, regardless of external disturbances. Wu's methodology involved extensive testing under varying field conditions to evaluate the responsiveness and stability of the feedback system, demonstrating that continuous sensing combined with automatic adjustment significantly enhances operational precision. One of the key advantages of this system is its ability to maintain a uniform application height, which is crucial in agricultural practices such as spraying fertilizers, herbicides, or pesticides. A consistent boom height ensures even distribution of chemicals across the crop field, preventing over-application in some areas and under-application in others. This not only improves crop health and yield but also minimizes chemical wastage and reduces environmental impact. Additionally, the automation of height adjustment reduces the need for manual intervention, thereby decreasing operator fatigue and human error.

Kamble S. and More R. (2024) developed a solar-powered mechanical pruner with a strong emphasis on sustainability and energy efficiency in agricultural practices. Their work focused on designing a pruning system that utilizes solar energy as its primary power source, thereby reducing dependency on conventional electricity and fuel-based systems. The methodology involved integrating photovoltaic panels with a mechanical cutting mechanism, where the energy captured from sunlight is converted into electrical power and either directly used or stored in a battery for later operation. The system was primarily manually operated, meaning that while the cutting action was assisted by solar-powered components, the positioning, height adjustment, and movement of the pruner relied on human effort. The design aimed to be simple, cost-effective, and accessible for small and medium-scale farmers, particularly in rural areas where electricity supply may be unreliable. Experimental evaluations demonstrated that the pruner could effectively perform basic cutting operations while maintaining low operational costs and minimal environmental impact. One of the major advantages of this system is its eco-friendly nature, as it harnesses renewable solar energy and eliminates the need for fossil fuels, thereby reducing carbon emissions. This makes it particularly suitable for sustainable agriculture practices. Additionally, the use of solar power helps in lowering long-term operational expenses, as farmers do not need to spend on fuel or electricity once the system is installed.

The device also reduces the physical effort required for pruning compared to completely manual tools, improving efficiency and productivity.

III. HARDWARE DESCRIPTION

3. Hardware Description

The Smart Height-Sensing Pruning Machine is developed using a combination of electronic and mechanical components that work together to achieve automated and precise pruning. Each hardware module is selected to ensure reliability, efficiency and suitability for agricultural field conditions.

3.1 Bluetooth Module

The system employs HC-05/HC-06 Bluetooth modules for wireless communication. These modules operate on the 2.4 GHz frequency band and utilize UART (serial communication) for data transmission. The HC-05 can function in both master and slave modes, while the HC-06 operates only in slave mode. They act as a bridge between the mobile device and the controller, enabling remote operation by converting serial data into wireless signals and vice versa.

3.2 Arduino Board (Controller)

The Arduino microcontroller serves as the central control unit of the system. It processes input signals from sensors and generates appropriate control signals for actuators such as motors. The controller ensures synchronization between sensing, movement, and cutting operations. Its ease of programming, real-time processing capability, and reliability make it suitable for embedded agricultural applications.

3.3 Ultrasonic Sensor (Height Sensing)

An ultrasonic sensor is used to measure the height of pigeon pea plants. It operates by emitting ultrasonic waves and calculating the distance based on the time taken for the echo to return. The sensor consists of four main pins: VCC (power supply), TRIG (trigger input), ECHO (output signal) and GND (ground). This non-contact measurement method enables accurate and consistent height detection under varying environmental conditions, ensuring precise pruning.

3.4 Servo Motor (Steering Mechanism)

The servo motor is utilized for steering control of the machine. It adjusts the angle of the front wheels based on control signals from the Arduino, enabling directional movement such as left and right turns. The servo provides precise angular positioning, which improves navigation and maneuverability in agricultural fields.

3.5 Single Shaft Gear Motors (Drive System)

Single shaft gear motors are used to drive the 8-wheel mechanism of the machine. These motors provide high torque output, allowing smooth movement across uneven terrain. The multi-wheel configuration enhances stability, traction and load distribution, ensuring efficient operation in field conditions. The motors are energy-efficient and designed for continuous use.

3.6 Blade Motor (Cutting Mechanism)

The blade motor is responsible for the pruning action. It drives a cutting blade at high speed to trim plant shoots at the desired height. The motor is mounted on an adjustable mechanism controlled by sensor input, ensuring uniform and precise cuts. Its robust design allows reliable operation in outdoor environments.

3.7 Battery Pack

The system uses a dual power supply consisting of 12 V and 5 V batteries. The 12 V battery powers high-load components such as drive motors and the blade motor, while the 5 V supply is used for low-power electronics including the Arduino and sensors. This separation ensures stable operation and reduces electrical noise.

3.8 Battery Management System (BMS)

A Battery Management System is integrated to monitor and protect the battery pack. It regulates parameters such as voltage, current and temperature, preventing overcharging, deep discharg and overheating. The BMS enhances battery lifespan, safety and overall system reliability.

3.9 Buck Converter

A buck converter is used to step down higher DC voltage to a stable lower voltage required by electronic components. It operates using switching techniques to achieve high efficiency. This ensures consistent power delivery and protects sensitive components from voltage fluctuations.

3.10 Chassis and Frame

The chassis is constructed using PVC sheets, providing a lightweight, durable, and corrosion-resistant structure. It supports all system components, including motors, sensors, and batteries. The design ensures proper balance and stability, especially for the 8-wheel configuration, enabling smooth operation on uneven agricultural land.

3.11 Remote Operation (Mobile Interface)

A mobile device serves as the user interface for remote control. Through a Bluetooth-enabled application, users can control movement, initiate pruning, and monitor system status. This reduces manual effort and enhances operational convenience.

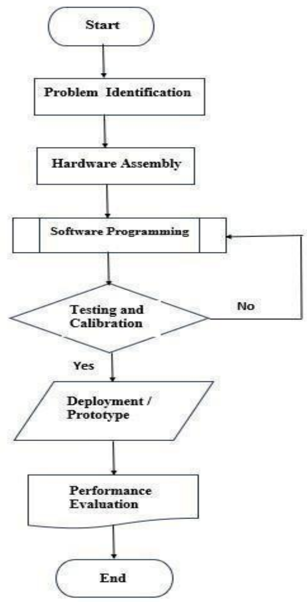
IV. METHODOLOGY

4.1 Start

The project begins by clearly identifying the main objective: to develop a Smart Height Sensing Pruning Machine that helps farmers prune pigeon pea plants more efficiently. At this stage, the need for reducing manual labour, improving accuracy and increasing crop yield is recognized. Based on this requirement, the concept of using sensors, microcontrollers and automation is finalized to create a reliable and farmer friendly pruning solution.

4.2 Problem Identification

The main problem identified is that manual pruning of pigeon pea plants is timeconsuming, labour intensive and often unsafe for farmers. Traditional pruning methods lead to irregular cutting, worker fatigue and lower yield due to inconsistent height maintenance. Farmers also face a shortage of labour during peak seasons, making manual pruning difficult to manage. These challenges highlight the need for an automated machine that can detect plant height accurately and prune shoots uniformly without depending on manual effort.



4.3 Hardware Assembly (Motors, Blade, Sensors, Chassis)

All essential hardware components are assembled to form the complete working structure of the machine. The gear motors are fixed to the 8-wheel setup for movement, while the blade motor is mounted securely for pruning. The ultrasonic sensor is positioned at the front to accurately detect plant height. The servo motor is linked to the blade mechanism for automatic height adjustment. Finally, the PVC chassis and frame hold all components in place, providing proper support, balance and stability for field operation.

4.4 Software Programming (ESP32 + Arduino + Remote Control)

The Bluetooth chip and Arduino are programmed to manage all sensor readings, motor actions and communication functions. The code processes ultrasonic sensor data to detect plant height and triggers the servo motor for automatic blade adjustment. Motor drivers are controlled through programmed logic for smooth movement of the 8-wheel system. Remote-control features are also added through Bluetooth chip for wireless operation.

Overall, the software ensures accurate height detection, stable cutting and easy user control.

4.5 Testing & Calibration

Each component of the machine is carefully tested to ensure accurate and reliable performance. The ultrasonic sensor is calibrated to measure plant height correctly, while the motors are adjusted for smooth movement and proper blade operation. The blade height is fine-tuned for consistent pruning and the entire system is checked for stability during field movement. Through repeated calibration, the machine achieves precise cutting and dependable real-world operation.

4.6 Field Deployment & Prototype Working

The fully assembled machine is taken to the pigeon pea field for real-world testing. The prototype is operated across different plant rows to check movement stability, height detection accuracy and pruning performance. The ultrasonic sensor measures plant height and the blade adjusts automatically while the robot moves forward. Field trials help evaluate cutting precision, battery performance and ease of operation. Based on this testing, necessary corrections and improvements are identified to make the machine ready for practical farming use.

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4.7 Performance Evaluation

The machine's overall performance is assessed by measuring its pruning accuracy, movement efficiency, energy consumption and impact on crop yield. Real-time field results help determine how effectively the sensor detects plant height and how consistently the blade cuts at the desired level. Battery usage, motor performance and operational safety are also evaluated. Based on these findings, necessary adjustments are made to improve precision, stability and overall efficiency, ensuring optimal performance in practical farming conditions.

4.8 End

The project concludes after completing all testing, calibration and performance evaluations. The final prototype is verified to work reliably in the field, meeting the objective of automating pigeon pea pruning. Documentation is prepared and the machine is ready for demonstration or further upgrades, marking the successful completion of the development cycle.

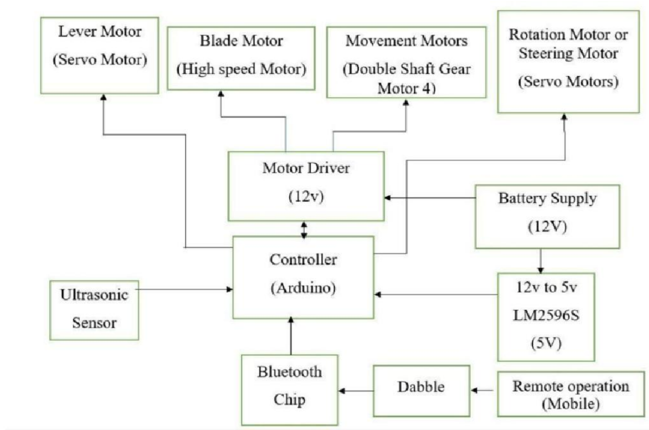

Fig. 1. Block Diagram of Smart Firework Controller System.

V. IMPLEMENTATION AND WORKING

5.1 Implementation

The Smart Height-Sensing Pruning Machine is implemented using a Bluetooth chip and Arduino to control the sensors and motors efficiently. The ultrasonic sensor continuously detects the height of the pigeon pea plants, while the servo motor automatically adjusts the blade position based on the sensor readings. The 8-wheel drive system, powered by singleshaft gear motors, provides smooth and stable movement across the field, even on uneven terrain. Once the plant height reaches the preset level, the blade motor activates to prune the shoots accurately and uniformly. The entire system is powered by rechargeable 12V and 5V batteries, ensuring long and stable operation. Additionally, the robot can be controlled remotely, allowing farmers to manage pruning from a safe distance. This implementation makes pruning faster, safer and more efficient, significantly reducing manual labor and improving crop yield.

5.2 Working

The Smart Height-Sensing Pruning Machine operates on the principle of automatic height detection and controlled pruning. The ultrasonic sensor continuously measures the height of pigeon pea plants and sends this information to the microcontroller. When the plant height exceeds the preset threshold, the Bluetooth chip processes the signal and instructs the servo motor to adjust the blade height accordingly. Once positioned, the blade motor activates and performs precise pruning of the shoots without harming the plant. The 8wheel single shaft gear motor system ensures smooth, stable movement across the field, even on uneven terrain. Power is supplied by two batteries a 12V battery for high-power components like motors and blade and a 5V battery for low-power electronics such as sensors and controllers. This setup ensures stable and efficient performance. The system's automation minimizes human effort, improves accuracy and prevents accidents during operation. With its reliable sensors and strong mechanical balance, the machine provides uniform pruning, promotes better plant growth and ultimately increases crop yield, making it a safe, smart and efficient solution for modern pigeon pea farming.

VI. CONCLUSION AND RESULT

6.1 Conclusion

The Smart Height Sensing Pruning Machine for Pigeon Pea crops successfully demonstrates how automation and modern technology can enhance agricultural productivity. The system integrates an microcontroller with ultrasonic height sensors, servos and an adjustable cutting blade to perform precise pruning based on real time plant height measurements. This automation eliminates the need for manual height estimation, reduces labour dependency and ensures uniform pruning across the field.

The machine's lightweight 8-wheel chassis provides stability and smooth movement across farmland, while safety features such as guards and an emergency switch protect the operator and crops during operation. The combination of mechanical design, electronics integration and software execution proves that technology such as microcontrollers and sensor systems can effectively support farmers in time-consuming tasks.

Field trials showed improved efficiency, reduced pruning time and more consistent plant growth, which contributes to increased yield potential. The machine also supports future scalability and can be upgraded with IoT-based data logging, GPS navigation, or solar power for sustainable operation.

Overall, this project demonstrates an innovative, farmer-friendly approach to crop management. It not only improves the accuracy and safety of pruning but also highlights how automation can play a significant role in the modernization of agriculture. This technology has the potential to benefit large farming communities and contributes to the vision of smart farming and precision agriculture**.**

6.2 Result

The Smart Height-Sensing Pruning Machine was successfully developed and tested under field-like conditions. The ultrasonic sensor accurately measured plant height, enabling the system to perform uniform and precise pruning. The integration of the Arduino controller, motors, and Bluetooth module ensured smooth operation and reliable remote control.

The machine demonstrated efficient movement across uneven terrain due to its 8-wheel drive system and provided consistent cutting performance with minimal human intervention. The use of a dual power supply system improved stability and prevented voltage fluctuations.

Overall, the system reduced manual effort, improved pruning accuracy, and enhanced operational safety. The results indicate that the proposed machine is effective for modern agricultural applications and contributes to increased productivity and efficiency.

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