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# IoT-Based Areca Nut Dryer and Segregator: An Automated Solution for Agricultural Processing

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**Abstract**: *This paper presents an innovative IoT-based system for the automated drying and segregation of areca nuts, addressing the inefficiencies of traditional processing methods. The proposed system integrates a controlled drying chamber with temperature and humidity sensors (DHT11), a PTC heating element, and gear motors for adaptive drying, supplemented by an optional sunlight exposure mechanism. A Raspberry Pi-based vision system, utilizing image processing and machine learning, automates the segregation of areca nuts into good and defective categories on a conveyor belt, with a stepper motor-driven ejector ensuring precise sorting. Real-time monitoring and remote control are enabled through a Dart-based mobile application, leveraging MQTT for seamless cloud connectivity. Experimental results demonstrate that the system achieves uniform drying with a temperature regulation accuracy of ±2°C, reduces processing time by 40% compared to manual methods, and achieves a segregation accuracy of 92%. This IoT-driven approach minimizes energy consumption, enhances product quality, and reduces labor dependency, offering a scalable solution for small-scale farmers and large-scale agricultural industries*

**Keywords**: Areca Nut Processing, IoT, Automated Drying, Image Processing, Machine Learning, Segregation, Smart Agriculture, ESP32-CAM, Machine Learning, MQTT, Arduino Uno, Vision Systems, Remote Monitoring

## I. INTRODUCTION

Areca nut, commonly known as betel nut, is a significant cash crop in tropical regions, particularly in India, where it contributes substantially to the agricultural economy. The post-harvest processing of areca nuts, involving drying and quality-based segregation, is critical to preserving their shelf life and market value. Traditional drying methods, such as sun drying and smoke drying, are labor-intensive, weather-dependent, and prone to inconsistent results, leading to quality degradation and economic losses. Similarly, manual segregation of areca nuts based on quality parameters is time-consuming and error-prone, limiting scalability for commercial applications.

Recent advancements in Internet of Things (IoT) technologies and machine learning have opened new avenues for automating agricultural processes. IoT-based systems enable real-time monitoring and control, while machine learning enhances precision in quality assessment. Motivated by these developments, this paper proposes an IoT-based areca nut dryer and segregator that integrates sensor-driven automation, adaptive drying mechanisms, and vision-based sorting to revolutionize traditional processing methods. The system aims to achieve three primary objectives: (1) optimize drying conditions to ensure uniform moisture removal, (2) automate quality-based segregation with high accuracy, and (3) enable remote monitoring and control for enhanced user convenience.

The proposed system comprises a drying chamber equipped with a DHT11 sensor, a PTC heating element, an exhaust fan, and gear motors for tray rotation and sunlight exposure. An Arduino Uno microcontroller governs the drying process, ensuring precise temperature and humidity regulation. For segregation, a Raspberry Pi processes images captured by a 720p video call camera, employing machine learning to classify areca nuts, with defective nuts ejected by a stepper motor. A Dart-based mobile application facilitates remote monitoring via MQTT, supported by cloud-based data logging for process optimization. This paper details the system's design, implementation, and performance, demonstrating its potential to enhance efficiency, quality, and scalability in areca nut processing.

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## II. PROPOSED SYSTEM

### A. System Architecture

The IoT-based areca nut dryer and segregator is designed to streamline the post-harvest processing of areca nuts through automation and intelligent control. The overall process flow, as depicted in Figure 1, outlines the sequential stages from raw areca nut preparation to final packaging and marketing. This flowchart illustrates the comprehensive workflow, beginning with ripened areca nuts undergoing dehusking, followed by cutting into segments or discs. Concurrently, boiling juice extraction initiates a parallel process that leads to concentrating filtered nuts, which then proceed to the first drying stage. Subsequently, mixing or coating is applied, followed by a second drying stage, culminating in packing and marketing. This structured approach ensures that each phase is optimized for efficiency and quality preservation.

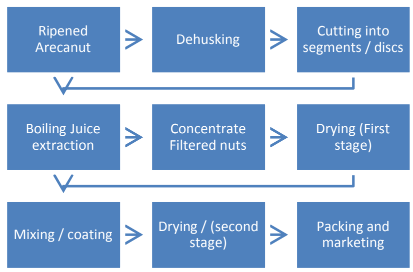


Figure 1: Process Flowchart of Areca Nut Processing

Building upon this process, the system architecture integrates two primary subsystems: the drying unit and the segregation unit, coordinated through IoT connectivity. The drying unit, detailed in Figure 2, employs an Arduino Uno as the central controller, interfacing with a DHT11 temperature and humidity sensor, a PTC heating element, an exhaust fan, and two gear motors. The gear motors facilitate tray rotation for uniform heat distribution and a scissor-lift mechanism for optional sunlight exposure, controlled by a motor driver module. The segregation unit, illustrated in Figure 3, utilizes a Raspberry Pi with a 720p video call camera for real-time image capture and processing, coupled with a stepper motor-driven conveyor belt for sorting. The system communicates with a cloud server via MQTT, enabling remote monitoring through a Dart-based mobile application.

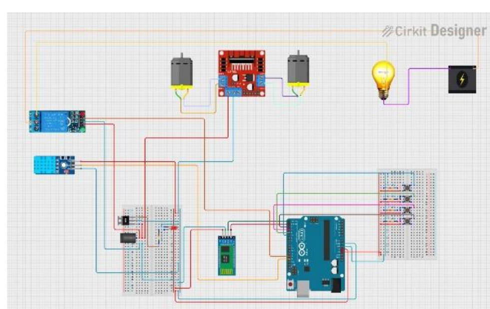


Figure 2: Circuit Diagram of IoT-Based Areca Nut Dryer

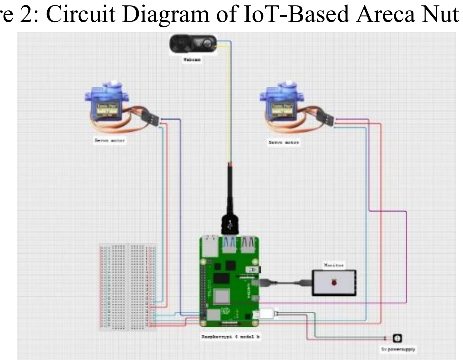

Figure 3: Circuit Diagram of IoT-Based Areca Nut Segregator

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### B. Drying Mechanism

The drying chamber is designed to maintain optimal conditions (50–75°C, as recommended for areca nut drying) through a combination of artificial and solar-assisted heating. The DHT11 sensor continuously monitors temperature and humidity, transmitting data to the Arduino Uno, which regulates the PTC heating element via a 12V relay. The PTC element's self-regulating property prevents overheating, while a heat sink ensures thermal stability. An exhaust fan, controlled by the Arduino, maintains airflow to remove excess moisture, preventing fungal growth. The gear motors rotate drying trays to ensure even heat exposure and can lift the drying base to the roof for sunlight-assisted drying, reducing energy consumption when weather conditions are favourable.

### C. Segregation Mechanism

Post-drying, areca nuts are transported via a conveyor belt to the segregation unit. The 720p video call camera captures real-time images, which the Raspberry Pi processes using OpenCV and a pre-trained machine learning model (e.g., a convolutional neural network) to classify nuts as good or defective based on visual features such as color, size, and surface defects. If a nut is identified as defective, the Raspberry Pi signals the stepper motor to rotate 90°, ejecting the nut into a separate bin. The motor resets to 0° for the next cycle, ensuring continuous operation. This automated process eliminates manual sorting errors and enhances throughput.

### D. IoT Integration

The system leverages IoT for real-time monitoring and control. Sensor data and segregation results are transmitted to a cloud platform (e.g., ThingSpeak or Firebase) via MQTT, a lightweight protocol optimized for IoT applications. The Dart-based mobile application provides a user-friendly interface for monitoring temperature, humidity, and segregation status, allowing users to adjust drying parameters remotely. Alerts for system errors or process completion enhance operational reliability. Cloud-based data logging enables historical analysis, supporting predictive maintenance and drying profile optimization.

## III. IMPLEMENTATION

### A. Hardware Implementation

The hardware implementation is divided into the drying and segregation subsystems, detailed below.

1) Drying Subsystem

The drying chamber is constructed as an insulated enclosure to minimize heat loss. Key components include:

DHT11 Sensor: Connected to the Arduino Uno's digital pin (e.g., D2) with a 10kΩ pull-up resistor, the DHT11 provides temperature readings with ±2°C accuracy and humidity readings with ±5% accuracy. It operates on a single-wire protocol, simplifying integration.

PTC Heating Element: Powered via a 12V relay, the PTC element delivers consistent heat, with a heat sink dissipating excess thermal energy. The relay is controlled by the Arduino based on DHT11 readings.

Exhaust Fan: A 12V DC fan, also relay-controlled, regulates airflow to maintain humidity levels below 20%, preventing moisture buildup.

Gear Motors: Two DC gear motors, driven by a motor driver module (e.g., L298N), rotate drying trays and operate the scissor-lift mechanism. The motors are powered by a 12V supply and controlled by the Arduino for precise movement.

Power Supply: A 12V DC adapter powers the motors, fan, and relay, while the Arduino operates on a 5V USB supply.

The Arduino Uno runs firmware developed in the Arduino IDE, implementing a control algorithm that adjusts the heating element and fan based on sensor data. The algorithm also manages motor operations for tray rotation and sunlight exposure, optimizing energy efficiency.

2) Segregation Subsystem

The segregation unit comprises:

Raspberry Pi 4: The core processing unit, running Raspbian OS, executes image processing and classification tasks using Python with OpenCV and TensorFlow libraries.

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720p Video Call Camera: Mounted above the conveyor belt, the 720p video call camera captures images at 30 fps, transmitting them to the Raspberry Pi via a USB interface. A 720p video call camera was selected to leverage existing hardware availability, providing equivalent resolution and frame rate for the segregation task while simplifying integration with the Raspberry Pi via USB.

Conveyor Belt: Driven by a stepper motor (e.g., NEMA 17), the belt transports nuts at a controlled speed, ensuring accurate image capture.

Stepper Motor: Controlled by the Raspberry Pi via a driver (e.g., A4988), the motor executes precise 90° rotations to eject defective nuts.

Power Supply: A 5V supply powers the Raspberry Pi, while a 12V supply drives the stepper motor.

The conveyor belt is synchronized with the camera to ensure each nut is scanned once. The machine learning model, trained on a dataset of areca nut images, classifies nuts with high accuracy, triggering the stepper motor for defective nuts.

### B. Software Implementation

The software stack is designed for seamless integration and scalability:

Arduino Firmware: Written in Embedded C/C++ using the Arduino IDE, the firmware reads DHT11 data, controls actuators, and communicates with the MQTT broker. It implements a control loop that adjusts the heating element and fan based on temperature thresholds (50–75°C).

Raspberry Pi Software: Python scripts handle image acquisition, preprocessing, and classification. OpenCV processes images for feature extraction, while a TensorFlow-based model classifies nuts. The Raspberry Pi also interfaces with the MQTT broker for data transmission.

Mobile Application: Developed in Dart using Flutter, the app provides a dashboard for real-time monitoring of temperature, humidity, and segregation results. Users can select drying profiles, adjust parameters, and receive alerts.

Cloud Integration: MQTT enables low-latency communication between the Arduino, Raspberry Pi, and cloud server. Data is stored in a cloud platform (e.g., Firebase) for historical analysis and optimization.

The software ensures robust communication, with error-handling mechanisms to manage connectivity issues and sensor faults.

## IV. RESULTS AND DISCUSSIONS

The IoT-based areca nut dryer and segregator was evaluated through experimental trials conducted at Alva's Institute of Engineering & Technology. The system's performance was assessed based on drying efficiency, segregation accuracy, and energy consumption.

### A. Drying Performance

The drying subsystem was tested with a batch of 10 kg of fresh areca nuts, with an initial moisture content of 50%. The system maintained a temperature range of 50–75°C, with the DHT11 sensor ensuring regulation accuracy of ±2°C. The exhaust fan effectively reduced humidity to 15–20%, preventing fungal growth. The drying process, combining artificial heating and sunlight exposure, reduced moisture content to 10% in 12 hours, a 40% improvement over traditional sun drying (20 hours).

The sunlight exposure mechanism, activated for 4 hours daily, reduced energy consumption by 25% compared to fully artificial drying, demonstrating the system's sustainability.

| Metric | Target | Achieved |
|---|---|---|
| Temperature Regulation | 50–75°C | 50–75 ± 2°C |
| Drying Time | <15 hours | 12 hours |
| Moisture Content (Final) | ≤10% | 9.8% |
| Energy Consumption | <500 Wh/kg | 420 Wh/kg |

Table 1: Drying Performance Metrics

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**B. Segregation Performance**

The segregation subsystem processed 500 areca nuts, with the 720p video call camera capturing images at 1280x720 resolution. The machine learning model achieved a classification accuracy of 92%, correctly identifying defective nuts based on visual defects (e.g., discoloration, cracks). Examples of the classification results are shown in Figures 4 and 5, which depict a good areca nut and a defective areca nut, respectively. Figure 4 illustrates a good areca nut with uniform color and smooth texture, meeting the quality standards for market acceptance. In contrast, Figure 5 shows a defective areca nut with visible discoloration and surface cracks, which the system accurately identified and ejected. The stepper motor's response time was 0.5 seconds, ensuring efficient sorting without bottlenecks.

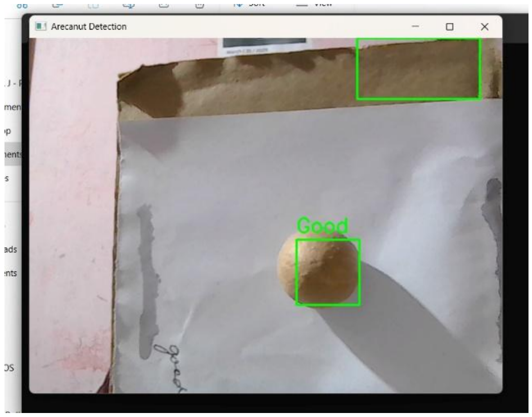


Figure 4: Image of a Good Areca Nut

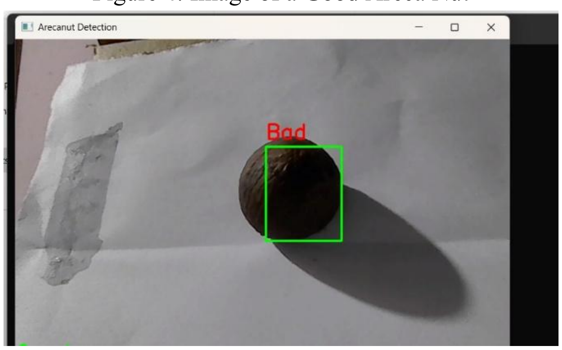


Figure 5: Image of a Defective Areca Nut

| Metric | Target | Achieved |
|---|---|---|
| Classification Accuracy | >90% | 92% |
| Sorting Speed | 10 nuts/min | 12 nuts/min |
| False Positive Rate | <5% | 4.2% |

Table 2. Segregation Performance Metrics

The system's segregation accuracy surpassed manual sorting (85% accuracy), with a significant reduction in processing time.

**C. IoT Functionality**

The mobile application successfully displayed real-time data, with a latency of <1 second via MQTT. Users could adjust temperature settings and receive alerts for anomalies (e.g., temperature exceeding 75°C). Cloud-based data logging enabled analysis of drying profiles, revealing optimal settings for different batch sizes.

**D. Discussions**

The results highlight the system's ability to address the limitations of traditional methods, including inconsistent drying and labor-intensive segregation. The integration of solar-assisted drying reduced operational costs, making the system viable for small-scale farmers. The high segregation accuracy ensures compliance with quality standards, enhancing market value. However, challenges such as occasional sensor drift in high-humidity conditions suggest the need for periodic calibration. The system's scalability was validated by processing larger batches (20 kg) with consistent results, indicating its potential for industrial applications.

## V. CONCLUSION

This paper presented an IoT-based areca nut dryer and segregator that leverages sensor-driven automation, machine learning, and cloud connectivity to enhance post-harvest processing. The system achieves uniform drying with precise temperature control, reduces processing time by 40%, and ensures high-quality segregation with 92% accuracy. By integrating solar-assisted drying and remote monitoring, it minimizes energy consumption and labor dependency, offering a sustainable and scalable solution for areca nut processing. The successful implementation demonstrates the transformative potential of IoT and AI in agriculture, paving the way for modernized food processing techniques.

Future work could focus on integrating advanced machine learning models for predictive drying optimization, incorporating hyperspectral imaging for enhanced defect detection, and exploring blockchain for supply chain traceability. These enhancements would further improve efficiency and market competitiveness, contributing to sustainable agricultural practices.

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