Qualitative Assessment of Fruit Harvesting Drone Fitted With Two Modes of End Effectors

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Abstract -Developing automatic fruit-plucking drones is imperative for efficient harvesting, combating labor shortages, and time constraints. Precision Farming necessitates drones equipped with suitable end effectors for fruit harvesting, capable of accurately detecting and classifying fruits. These drones must maintain stability during flight and be remotely controllable. Integration of a robotic arm with gripper enhances the harvesting process, capable of lifting payloads up to 1kg and moving within a range of 0.5m. Fruit detection relies on training object detection algorithms like SSD-Lite using various fruit images. The system employs a camera for fruit detection, processing frames at a rate of 4 per second. The robotic arm, with a soft gripper and top blades, ensures gentle fruit detachment without damage. Implementation of this system across orchards, encompassing fruits such as apples, bananas, guavas, and citrus, promises significant reductions in manual labor, time, and costs, benefiting agricultural practices extensively.

Key word: Fruit Harvesting Drone, Precision Farming, End Effector, Soft Gripper

I. INTRODUCTION

In light of a projected global population surpassing 9 billion by 2050, agriculture assumes a critical role in ensuring food security. Embracing sustainable farming practices becomes imperative to meet escalating food demands. Agriculture stands as a pivotal contributor to climate change mitigation efforts, with practices like agro-forestry, crop rotation, and organic farming offering avenues for carbon sequestration, greenhouse gas reduction, and soil health improvement. With millions worldwide reliant on agriculture for livelihoods, particularly in developing nations, investments in agricultural infrastructure, technology, and education hold potential to spur economic growth, alleviate poverty, and enhance rural well-being. Addressing labor-intensive conventional practices, the agricultural sector should pursue diverse avenues including technological advancements like agricultural robotics, ensuring sustainable production while safeguarding the safety of farmers and laborers. Robotics applications encompass tasks from transplanting to harvesting, with developments evident in both developed nations and emerging economies like India.

Enhancing farmer efficiency through technological advancements, particularly involving smart devices, sensors, and intelligent machinery, is paramount. Improved crop monitoring, facilitated by sensors like temperature and moisture sensors, aerial imaging, and GPS technologies, enables mapping and automated spraying for enhanced agricultural productivity. The adoption of advanced technologies, robotic systems, and precision agriculture heralds a transformative shift in the agricultural sector, fostering increased profitability, safety, efficiency, and environmental sustainability. This project leverages modern technologies such as drone surveillance and pesticide application, coupled with image processing techniques and optimized spraying nozzles, to optimize crop yield, quality, and farmer revenue.

1.1 Precision Agriculture:

Precision agriculture, also known as precision farming or smart farming, refers to the use of technology, data, and advanced farming practices to optimize crop yields, reduce input costs, and minimize environmental impacts. This approach involves gathering and analyzing data on factors such as soil conditions, weather patterns, crop health, and field variability to make informed decisions about crop management.

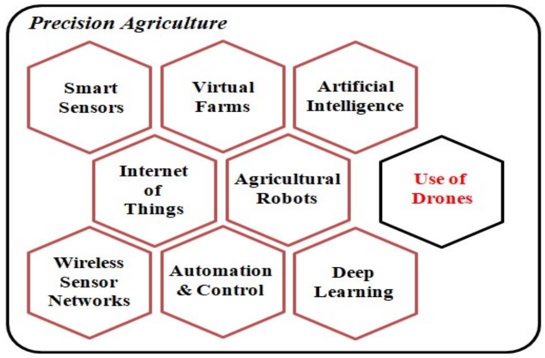

Fig 1: Precision Agriculture

In today's tech-driven world, revolutionizing agriculture is imperative, and drones are pivotal in this transformation. Drones serve multiple roles, from seeding to pesticide application, optimizing agricultural processes, monitoring crop development, and boosting yields. Surveillance drones play a vital role in monitoring plant health and identifying pests and insects, while AI-enabled drones assess soil moisture, fertility, and other factors affecting plant growth. Embracing the latest agricultural technologies is crucial given population growth and changing weather patterns. Drones offer significant advantages in agriculture, enhancing both the quantity and quality of traditional farming and increasing revenue through drone-based monitoring of farmland.

1.2 Uses of Drones In Agriculture:

a. Soil and field Analysis

For efficient field planning, agricultural drones can be used for soil and field analysis. They can be used to mount sensors to evaluate moisture content in the soil, terrain conditions, soil conditions, soil erosion, nutrients content, and fertility of the soil.

b. Crop Monitoring:

Crop surveillance is the supervision of crop progress from the time seeds are sown to the time for harvest. This includes providing fertilizers at the right time, checking for pest attack, and monitoring the effect of weather conditions. Crop surveillance is the only way that a farmer can ensure a timely harvest, especially when dealing with seasonal crops.

c. Plantation:

Drones can help in planting trees and crops, which was done by farmers before. This technology will not only save labor but also help in saving fuels. Soon, it is expected that budget-friendly drones will be used instead of huge tractors, as they emit harmful gases and pollute the environment in the process.

d. Livestock Management:

Drones can be used to monitor and manage huge livestock as their sensors have high-resolution infrared cameras, which can detect a sick animal and swiftly take actions accordingly. So, the impact of drones on precision dairy farming is soon to become a new normal.

e. Crop Spraying:

Agri-drones can be used to spray chemicals as they have reservoirs, which can be filled with fertilizers and pesticides for spraying on crops in very little time, as compared to traditional methods. Thus, drone technology can usher in a new era for precision agriculture.

f. Check Crop Health:

Farming is a large-scale activity that takes place over acres of land. Constant surveys are necessary to monitor the health of the soil and the crop that has been planted. Manually, this may take days, and even then, there is space for human error. Drones can do the same job in a matter of hours. With infrared mapping, drones can gather information about both the health of the soil and the crop.

g. Avoiding Overuse of Chemicals:

Drones can prove to be especially effective in reducing the overuse of pesticides, insecticides, and other chemicals. These chemicals indeed help to protect the crop. But, their overuse can prove to be detrimental. Drones can detect minute signs of pest attacks, and provide accurate data regarding the degree and range of the attack. This can help farmers calculate the required amount of chemicals to be used that would only protect the crops rather than harming them.

h. Growth Monitoring:
Even when everything is going according to plan, crops need to be surveyed and monitored to ensure that the right amount of yield will be available at the time of harvest. It is also important for future planning, whether it is about determining the right price for the open market, or harvesting cyclical crops.
Drones can provide accurate data about every stage of crop growth, and report any variations before they become a crisis. Multispectral images can also provide accurate information about subtle differences between healthy and unhealthy crops that may be missed by the naked eye. For example, stressed crops will reflect less near-infrared light as compared to healthy crops.

1.3 Need for Automations in Fruit Harvesting:

The necessity for automation in fruit harvesting arises from several factors. Harvesting is characterized by seasonal, repetitive, and labor-intensive tasks, often with low pay and limited professional prospects. With experienced harvesters retiring and a lack of interest among younger individuals to replace them, labor shortages lead to delays in harvesting. These delays can significantly impact fruit quality, causing a loss of up to 80% of market value, amounting to an estimated USD 30 billion in lost sales annually. To address these challenges, the agricultural landscape has witnessed a shift towards automation, incorporating ground and aerial robots to automate manual operations, including harvesting. Robotic systems aim to mitigate labor shortages, increase harvesting speed, and enhance efficiency. While manual harvesting relies on human skills such as hand-eye coordination and tactile sensitivity, robotic systems offer continuous, accurate, and tireless performance. Researchers strive to replicate human harvesting skills through kinematic models for robotic arm movement and the development of advanced end effectors equipped with sensors for precise crop manipulation.

II. LITERATURE SURVEY

Smith, J. et.al in 2020, provides an overview of the various robotic systems developed for fruit harvesting. They cover topics such as design considerations, end effector development, sensing technologies, and challenges faced in implementation. Their paper offers insights into the current state of fruit harvesting robotics and identifies areas for future research. [1]

Garcia, M., Martinez, B., & Lopez, R. in 2019 focus on the use of autonomous aerial robots, including drones, in precision agriculture. They discuss the potential applications of drones in fruit harvesting, such as monitoring crop health, mapping orchards, and delivering payloads. Their paper highlights the advancements in drone technology and their impact on agricultural practices.[2]

Wang, H., Li, Y., & Zhang, L. in 2018 examine the use of vision-based systems for fruit detection and localization in robotic harvesting applications. They discuss various techniques, including machine learning algorithms and image processing methods, used to identify and locate fruits in orchards. Their paper evaluates the performance of these systems and identifies areas for improvement. [3]

Andrews 2018 investigates the effect of artificial intelligence in agricultural zones. The factors influencing the growth of crops are changes in temperature, pH value of soil, climatic condition, and availability of water are considered for implementing artificial intelligence in agriculture. There is a need to increase the production of food products to overcome food scarcity. The solution to the problem is to evolve artificial intelligence into the field of agriculture. Artificial intelligent based farming gives information about the harvesting period, type of crop to be cultivated, when to cultivate the crop, rotational crop development, seeding period, control of weeds, disease in plants. [4]

Kim, S., Park, J., & Lee, S in 2020 explored the integration of unmanned aerial vehicles (UAVs) and robotics in precision agriculture, with a focus on fruit harvesting applications. They enumerated the advantages of using UAVs for aerial imaging and navigation, as well as the challenges associated with integrating robotics for ground-based tasks such as harvesting. Their paper presented case studies and identified future research directions.[5]

Turrini, F., et.al in 2019 presents the design and development of a drone specifically tailored for automatic harvesting of cherry tomatoes. They discuss the integration of robotic arms and computer vision systems into the drone platform to enable precise and efficient fruit harvesting. [6]
Muthukumaran, N et.al in 2020 describes the design and implementation of a vision-based fruit harvesting robot. They explain the integration of computer vision algorithms for fruit detection and localization, as well as the robotic arm mechanism for harvesting, offering insights into the development of such systems. [7]
Shafiekhani, A., et al. 2019 provide an overview of fruit harvesting robots, including their design, mechanisms, and applications. They provide surveys on various robotic systems developed for fruit harvesting and evaluates their performance and effectiveness in different agricultural settings. [8]
Chen, T., Liu, Q., & Wang, X in 2021 present the development of a robotic arm specifically designed for fruit harvesting. Their paper discusses the challenges encountered in designing an efficient end effector, ensuring gentle fruit handling, and integrating the robotic arm with a drone platform. The paper provides insights into the technical aspects of robotic fruit harvesting systems. [9]

III. STRUCTURE OF FRUIT HARVESTING DRONE

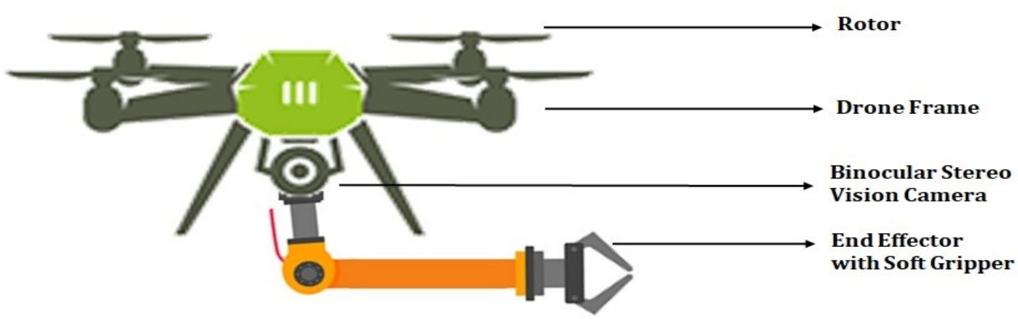

Fig 2: Components of Fruit Harvesting Drone

a. Vision Systems: Fruit harvesting drones are equipped with advanced vision systems, including cameras and sensors, capable of identifying ripe fruits based on color, size, and other visual characteristics. These systems enable the drone to locate and target fruits for harvesting accurately.

b. Manipulator Arms: Harvesting drones are often equipped with manipulator arms or grippers designed to gently grasp and detach fruits from the tree branches. These arms are engineered to mimic the delicate touch of human hands, ensuring that fruits are harvested without bruising or damage.
c. Navigation and Maneuverability: Fruit harvesting drones are designed to navigate through orchards or vineyards with precision and agility, maneuvering around obstacles such as tree branches and foliage. Advanced navigation systems, including GPS and obstacle avoidance technology, enable the drone to fly safely and autonomously while harvesting fruits.

d. Payload Capacity: Harvesting drones are equipped with payload capacities suited to carry harvested fruits. Depending on the size and design of the drone, it may be capable of carrying a significant payload of harvested fruits before needing to return to a collection point.

e. Real-time Data Analysis: Some fruit harvesting drones are equipped with onboard data processing capabilities, allowing them to analyze fruit ripeness and quality in real-time. This analysis can help optimize harvesting operations by prioritizing the collection of ripe fruits and avoiding harvesting unripe or damaged fruits.

f. Autonomous Operation: Fruit harvesting drones are designed for autonomous operation, requiring minimal human intervention. Once programmed with the orchard layout and harvesting parameters, the drone can autonomously navigate, identify, and harvest fruits without the need for manual control.

IV. END EFFECTORS

An effective harvesting system must balance between speed and efficiency. The most important of these requirements include:

a. Operational characteristics: adaptation to various shapes, not causing damage to the harvesting product and high precision of operations.
b. Technical characteristics: high activation speed, low maintenance, low weight, and low energy consumption.

The paper deals with a review of fruit detachment methods to highlight the necessary features of an efficient end effector. Subsequently, the most prevalent types of end effectors that fulfill the requirements for fruit harvesting are summarized. End effectors are categorized into grippers or tools. Grippers enable temporary direct contact with the target product, either from the fruit body or the stem. Vacuums, functioning as properly constructed suction devices, are also considered as types of grippers, albeit without involving actual grasping (indirect harvesting). For the purpose of this study, grippers will be exclusively regarded as devices facilitating direct grasping.

The end effectors in this work are grouped into the following four categories according to detachment method: a) Contact-grasping grippers, Fruit holding or stem holding, b) Rotation mechanisms c) Scissors/Saw-like tools, d) Suction devices

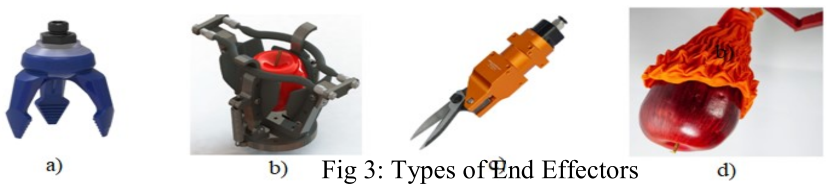

Fig 3: Types of End Effectors

V. DESIGN & METHODOLOGY

This section outlines the fundamental dynamics of a Quadcopter, along with its control concept. The figure provided illustrates the basic movement of the Quadcopter. Unlike helicopters, Quadcopters exhibit simpler mechanical designs. Horizontal movement is attained by tilting the platform, while vertical movement is accomplished by adjusting the overall thrust generated by the motors.

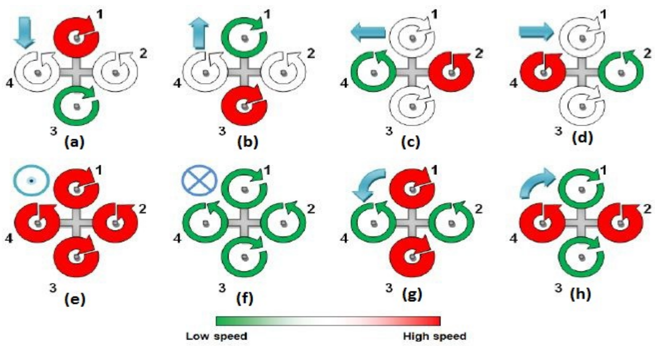

Fig 4: Basic Flight movements of a Quadcopter [10]

5.1 Overall Weight Estimation:

The performance of Quadcopter is mainly dependent on the ratio between overall weights to payload. This ratio is very essential to calculate the flight parameters such as thrust, power, speed, and endurance of which thrust is the major factor needs to be calculated.

$W_{Payload} = W_{Primary} + W_{Secondary}$

$W_{Primary}$ = Fruit Weight = 120 to 250 gm = 0.12 – 0.25 kg

$W_{Secondary}$ = Robotic Arm Weight = 1.25 kg

$W_{Payload}$ = 1.25 kg + 0.25 kg = 1.50 kg

As Wo/WP of commercially available drones are in the range of 2.4 to 2.8, it was decided to design the proposed system to have Wo/Wp at 2.55 as it provides low weight and subsequently offer better endurance. Therefore,

$$\frac{W_0}{W_P} = 2.55$$

$$W_0 = 2.55 \times 1.50\ kg = 3.825\ kg$$

5.2 Calculation of Diameter of the Propeller:

The propeller serves as the sole component responsible for generating thrust in the drone, converting the motor's rotary motion into linear thrust. This lift is achieved by creating a pressure differential between the upper and lower surfaces of the propellers. Adjusting the propellers' speed enables the drone to maneuver in various directions, including roll, pitch, yaw, hover, take-off, and landing. The number of propellers varies depending on the drone's configuration, with Quadcopters typically equipped with four propellers.. The materials of the blades are of carbon fibre or plastic. Plastic propellers are more flexible and less durable than carbon fibre. Carbon fibres are light in weight compared to plastic, and they also reduce the vibration caused due to rotation of blades.

We know that,

$$T_{Propeller} = \frac{\left[\frac{T}{W}\ Ratio\right] \times \left[W_{Overall\ Take\ Off}\right]}{n}$$

Where, $T_{Propeller}$ = Thrust Requirement by a single propeller

T/W = Thrust to Weight Ratio

n = Number of Propellers

It is important to mention that the higher the thrust to weight ratio will offer better controllability. Generally, the minimum thrust to weight ratio for agricultural drones is 1:2 to perform all kinds of aerodynamics maneuvering and to hover at half the throttle [11]. Hence T/W is selected as 2 for optimal performance.

$$T_{Propeller} = \frac{2\ \times 3.825}{4} = 1.915\ kg$$

Therefore Thrust Requirement for single propeller is 1.915 kg.

From the thrust requirement, the diameter (length) of the propeller can be calculated using the following equation based on the momentum theory

$$T = 0.5 \times \rho \times A \times \left[\left({V_{UAV}}^2 - {V_0}^2\right)\right]\ \ (N)$$

Where $\rho = 1.225\ kg/m^3$ – Density of Air

A – Area of Propeller

V_{UAV} – Velocity of air accelerated by propeller

V_0 – Velocity of air at the propeller

T – Thrust = 1.915 kg x 9.81 = 18.76 N

$$0.5 \times 1.225\ \times A \times\ [(24^2 - 5^2)] = 18.76$$

$A = 0.0555\ m^2$

$\pi r^2 = 0.0555$ =

r = 0.133 m ≈ 13 cm

Diameter = 26 cm = 10 Inches

5.3 Calculation Of Pitch Of The Propeller

Under the design consideration of the propeller, the pitch of the propeller plays the vital position along with diameter. There were twenty propeller profiles used for agricultural drones that are available in the market were collected and the relationship between various propellers to pitch by diameter (P/D) ratio is studied.

From the study, it is observed that most of the pitches to diameter fractions are located in the range between 0.35 and 0.40. In this work, P/D was arbitrarily chosen as 0.375 and the pitch was calculated as given

P/D=0.375

P = 0.375 x 10 inches = 3.75 inches

Sensor units

BLDC Motor	1400 Kv
Electronics Speed Controller	30 A
Thrust to weight ratio	1:2
Gimbal	3 axis
Flight control Board	Pixhawk 2.4.8
Frame	350mm * 350mm * 100mm
Maximum speed	25 m/s
Range	900 - 1100 ft
Power unit	
Battery	8000 mAh
Operating time	20 Mins
Propeller unit	
No of propeller	4
Propeller size 8	10 inch length * 4 inch pitch
Operational mode and weight	
Net weight	2 kg
Operational mode	Semi-Autonmous

Table 1: Major Components Specifications

5.4 Design of End Effector:

Once a fruit is detected and located, the challenge is to pick it without damaging the fruit or the crop. Typically, fruits are difficult to reach due to many unstructured obstacles that interfere with the harvesting system, such as branches and leaves. An effective harvesting system must balance between speed and efficiency. A key component of any harvesting mechanism is a harvesting end effector that detaches a fruit from a tree. It is common for end effectors to be customized based on the harvested crop. However, the design can be adapted to other crops of the same fruit size or can be adjusted to different fruits with minor readjustments.

a. *Design Of Soft Gripper:*

In the gripper design, we aim to achieve reliable grasping from the compliant nature of the proposed soft actuators, while maintaining a simple structure. A tri-finger-single-palm setup was selected, with reference to the thumb, index and middle finger as the most important fingers in grasping. There is a 120 degree angle between each pair of adjacent fingers. The design parameters and modeling variables of the soft gripper are shown.

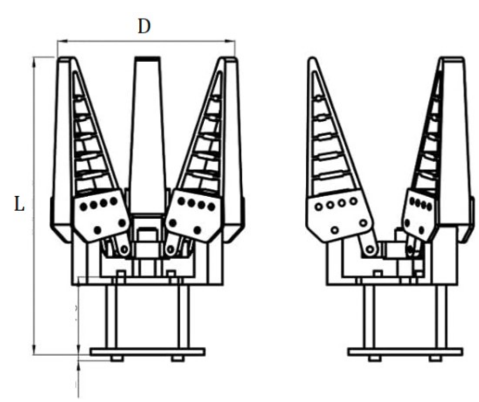

Fig 5: Three Finger Gripping End Effector

b. *Design Of Pruning Cutter*:

Pruning cutter end effector can be modeled as a rigid body with six degrees of freedom, linear translation along the inertial and axes, and three degrees of freedom describing the rotation of the body reference frame respect to the inertial reference frame.

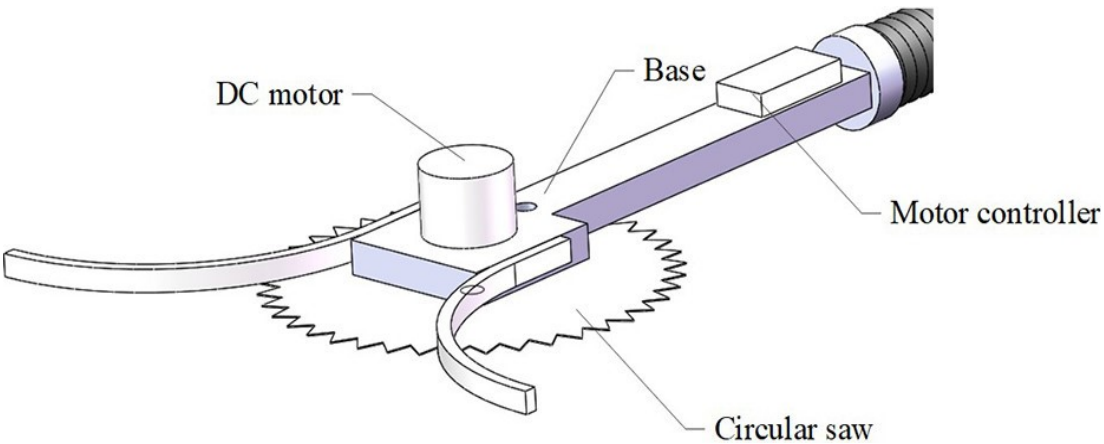

Fig 5: Single Blade Pruning Cutter End Effector

VI. CONCLUSION

While the shortage of labor is driving the demand for automation in harvesting operations, the emerging capabilities for harvesting with high consistency and speed motivates research for UAV harvesting solutions. Moreover, the introduction of new modern technological trends in the agricultural sector could potentially attract a new generation of farmers, as older generations of farmers retire.

This paper reviewed the latest developments in the implementation of end effectors in real-world aerial harvesting operations. In this project, we designed and developed a Fruit harvesting drone with two modes of end effectors. The function of the fruit harvesting drone is defined in the simplest of way which enables the end effector to perform a specific task. The materials and parts selection have been considered based on detailed evaluation of drones available in the market along with the mass of payload to be carried.

The end-effector is modeled such that it is equipped with grippers which give a better grip to the object help by the arm also the arm is stationary with the links being adjusted manually. Cutter arm is provided and tested for heavier tree branches. The drone model presented here is controlled by means of a remote, where further developments can be pursued to have a complete autonomous system with capabilities of self-positioning, tracking and voice control of the drone.

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