Problem to solve

Fruit harvesting remains highly dependent on seasonal manual labor, making growers particularly vulnerable to labor shortages, rising labor costs, and unpredictable weather conditions. According to reports published by the World Wildlife Fund (WWF), labor availability is consistently identified by growers as the primary limiting factor preventing surplus produce from being harvested. Mechanization could therefore be identified as one viable long-term solution, particularly within the United States, where the average minimum wage for agriculture workers is $15 or higher and has been growing in recent years [1].

Studies estimate that approximately 15–20% of fruit remains unharvested in the field [2], while 40–50% of fruits, vegetables, and root crops produced globally are ultimately lost or wasted. This represents not only a significant financial loss for growers but also a major environmental issue, considering the water, energy, fertilizer, land, and labor already invested in producing these crops. **As global food demand continues to rise, reducing food loss through intelligent automation becomes increasingly important for building next-level agricultural systems.**

In addition to this, harvest periods are also characterized by extremely demanding workloads. Growers often describe harvest seasons as operating under constant pressure, leaving little capacity to manage additional logistical challenges that arise [2]. An autonomous harvesting system capable of supplementing or replacing manual labor could reduce operational stress on farmers, increase harvesting efficiency, and allow farms to recover produce that would otherwise remain in the field.

The histogram in Figure 1, highlights the top 3 US states per peaches production for the year 2022 [3] with California leading the way with 475000 tons of peaches produced, followed by South Carolina with 67400 tons and Georgia with 24800 tons. As shown in Figure 1, the green portions of the histogram's bars represent the estimated increase in harvested peach quantity that could be achieved through an efficient method of mechanization. Assuming that approximately 15% of peaches currently remain unharvested due to labor and operational constraints, an autonomous harvesting solution could really increase the amount of produce ready to be sold on the market.

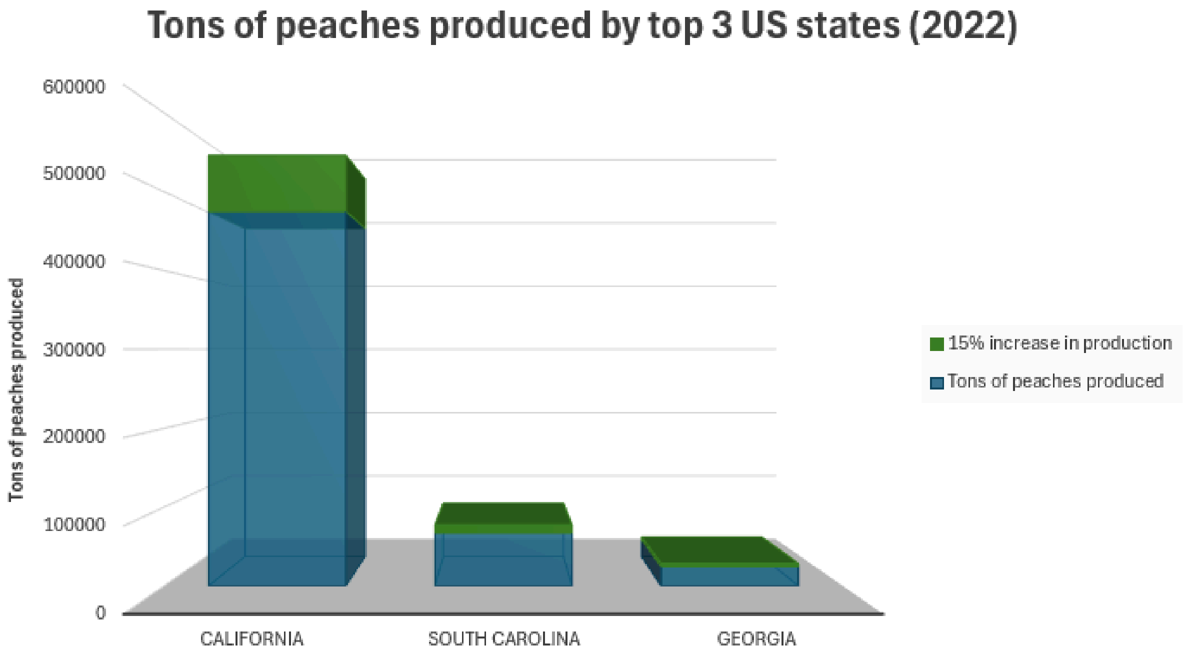

Figure 1: *Histogram showing tons of peaches produces by California, South Carolina and Georgia*

Idea summary

This document proposes the development of an **autonomous aerial robotic harvesting platform that combines the mobility of a drone with the dexterity of a robotic manipulator**. Unlike conventional agricultural drones primarily designed for spraying or imaging, this system would physically harvest fruit directly from trees.

The Drone-Robot (DROT) system would integrate:

- An quadcopter drone;
- A lightweight robotic arm with an end-effector designed for fruit harvesting;
- Artificial intelligence and computer vision algorithms for fruit detection, localization, maturity estimation and grasp planning;
- Autonomous navigation and motion planning for safe interaction with trees, dynamic environments, and other drones;

Since only Tevel Aerobotics Technologies has demonstrated the feasibility of autonomous aerial fruit harvesting [4], there is significant opportunity for innovation in lightweight aerial manipulation applied to agriculture and to the harvesting of different fruit varieties.

Ultimately, this concept aims to integrate artificial intelligence, aerial robotics, and autonomous manipulation to make the harvesting of hard-skinned fruits more predictable and economically efficient, while simultaneously reducing fruit waste.

Getting the components

The initial objective is to rapidly develop a functional proof-of-concept capable of validating the aerial manipulation idea while minimizing both development time and cost.

For the first prototype, the structural components—including the frame, arms, chassis, and the robotic arms' components—will be manufactured using 3D printing. This enables rapid design iterations, quick replacement of damaged components, and allows for low manufacturing costs during the early development.

As the design matures, structural components will transition to lightweight composite materials such as carbon fiber to improve stiffness and durability of the system while reducing its weight. Protective components such as the canopy will be manufactured using flexible TPU, while propeller guards may consist of lightweight plastic or foam. For harvesting operations inside tree canopies, enclosed propeller designs similar to the DJI Neo 2 could improve operational safety by avoiding and shielding the propellers from coming into contact with branches and foliage (this is what Tevel Aerobotics has done in their drone design).

Standard components such as propellers, motors, electronic speed controllers (ESCs), fasteners, and other hardware will be initially purchased off-the-shelf or online depending on whichever of the two provides the highest quality for the lowest cost.

Design process

The DROT system will be designed using CREO Parametric as the main CAD software.

The design process will focus on:

- Lightweight structural design
- Manufacturability
- Ease of assembly
- Modularity

A modular architecture will allow different robotic manipulators, and payloads to be integrated depending on the target application as the robotic arm on the DROT system could be utilized in fields other than agriculture in the future.

Figure 2: *Visual 3D representation of the DROT system.*

Analysis

Before manufacturing production-ready components, structural analyses will be performed to verify the design.

These analyses include:

- Static structural analysis
- Stress analysis
- Strain analysis
- Deformation analysis
- Factor of safety calculations
- Load distribution throughout the frame
- Dynamic loading during flight

Special attention will be given to the analysis of the robotic arm since extending the arm shifts the drone's center of gravity and creates significant bending moments on the frame which will need to be counterbalanced by the propellers.

Validation will combine:

- Finite Element Analysis (ANSYS)
- Classical engineering calculations
- Experimental testing

Propeller and airflow optimization may later be investigated using Computational Fluid Dynamics (CFD) to improve propulsion efficiency and aerodynamic performance.

Minimum Viable Product (MVP)

The first flight-capable prototype will be designed around a limited set of engineering requirements.

Minimum Requirements

- Payload capacity of at least 350 g
    - Sufficient for handling an apple, a peach, a pear, or lightweight industrial tools(for future applications)
- Minimum flight endurance of 30 minutes
- Operational range of minimum 5 km
- Autonomous takeoff and landing
- Autonomous waypoint navigation
- Autonomous fruit detection
- Autonomous fruit picking
- Autonomous placement of harvested fruit into a container or collection bin on the ground

Software

The software stack will be based primarily on open-source technologies to accelerate development and reduce costs.

Potential architecture:

Flight Controller

- ArduPilot

Onboard Computer

- Raspberry Pi (could change depending on the computational requirements of the system)

Computer Vision

- CNN based object detection system YOLO

Navigation

- GPS
- Visual localization using camera/s

Potential algorithms for path planning include:

- RRT*
- PRM
- A*
- D* Lite

The final path planning algorithm will be selected based on computational efficiency, obstacle avoidance performance, and compatibility with orchard environments. More research needs to be done on this subject.

Development strategy

Two possible development paths are currently being considered.

Option 1 – Build from Scratch

Design and manufacture most structural components internally.

Advantages:

- Complete design freedom
- Better long-term scalability

Disadvantages:

- Higher development cost
- Longer development timeline

Option 2 – Integration of Existing Components

Assemble a prototype using commercially available drones and robotic manipulators.

Advantages:

- Faster proof of concept
- Lower initial investment

- Earlier customer validation
- Faster market entry

Disadvantages:

- Less optimized design
- Greater dependency on third-party hardware

This approach may be the most effective strategy for validating the concept and generating early customer interest before investing in a full creation of the hybrid.

Market discovery and Future Work

Although the initial application of DROT is autonomous fruit harvesting, the underlying technology—a drone capable of aerial manipulation—has potential across multiple industries.

Potential markets include:

- Agriculture
- Industrial inspection
- Infrastructure maintenance
- Construction
- Search and rescue missions
- Hazardous environment operations
- Defense
- Logistics

While the long-term vision for the Drone-Robot hybrid platform spans multiple applications, seeking all of these opportunities simultaneously would greatly increase the technical difficulty of the system and increase the manufacturing time of the same. Therefore, the initial development efforts will focus on solving a single problem, that is, building a more efficient, and cost-effective solution for harvesting hard-skinned fruits.

Sources

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