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# A Comprehensive Survey on Methods and Techniques for Automated Fruit Plucking

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**Abstract:** In comparison of various product types in the farming, fruit farming has been more challenging than grain farming due to the challenges in its cultivation, harvesting in unstructured environment, high cost of safety during storage and timely distribution due to their short life. Fruit plucking becomes an important part due to its direct relation with the safety of potential return on farmer's investment. After humans started farming, there is step by step changes in fruit plucking techniques. Regardless, this process still remains labor intensive and manual in nature. The population on world is growing at rapid pace and so is the world-wide demand of agricultural products. However, labor shortages have remained a limiting factor in agriculture production. To cope up with the upcoming growth as well as to reduce the wastage of perishable items like fruits, it's important that the agriculture sector brings further automation. Sector needs to tackle the common fruit picking challenges through novel system solutions and improve the current systems. This paper shows the changes and growth in plucking techniques from ancient times to modern day plucking. Paper reviews the manual plucking techniques that involves the intensive risk and crude equipment with manual labors, to modern fruit plucking techniques based on computer vision and robotic systems. From this review, this paper intends to identify major research opportunities that are drafted under future research directions section.

***Keywords:*** *Fruit Harvesting Techniques, Cost, Efficiency, Manual Harvesting, Computer Vision, Robotic Systems, Mechanical Harvesting.*

## 1. Introduction

The process of detaching agricultural commodities deliberately from their mother plants for the intention of consumption or sale or other purposes is called as harvesting. Fruit harvesting process includes multiple decisions that impact the optimal economic yield of the crop, viz: 1) Identification and judging maturity of fruits, 2) detachment / plucking process and 3) safe storage/collection of matured fruits. The extent and risk of these decisions varies based on type of fruits. Tree fruits often utilize shake and grab techniques. Vine fruits use a bit delicate and multi-stage approach in fruit plucking. Bush fruits provide a larger scope of machines and mass harvesting. As per WWF (world wildlife fund) study in 2021, 15.3% of food produced world-wide is lost during the harvest and slaughter operations [1]. Through local research and innovation, there are two major streams of studies that reduce the cost and improve economic yield of fruit harvesting. Those are mechanical harvester and automatic harvester.

Mechanical harvesting involves using machines like air blast, mass cutters to harvest fruits. They are utilized for mass harvesting and are often a choice for fast turnaround. Mechanical harvesters are messy, lack the ability to select quality products and often collect a considerable debris/unripe fruit with the usable fruits. It requires post-harvesting cleaning and selection process, which again relies on manual inspections. Mechanical harvesters are a good choice when the much-called debris is usable in other industries like fodder, medicine, farm manure, etc. There is semi-mechanical harvesting with varying involvement and decision making of human operator.

Automated harvesting was studied back in 1960s when Schertz and Brown in suggested the use of robotic picking devices for citrus harvest [2]. They proposed a machine learning system that puts the mechanical robotic fruit manipulators in the harvesting range of the fruit. This problem of fruit selection, location understanding, navigating manipulator till the fruit and right manipulation technique increases the complexity of automated systems. Additionally, the natural environment for fruit plucking is complex and unstructured. The limitations of sensors and lack of robust methodology to solve for end-to-end challenges make automation even more difficult. Hence, this paper focuses on the review of research/opportunities in the advanced computer vision techniques and utilization of common available sensors in automated fruit plucking techniques.

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Further paper is categorised in four parts – first two parts discuss the application and evolution of manual harvesting and mechanical harvesting techniques respectively. Third part discusses the research and development of automatic harvesting. Part four continues to share the advancements, benefits/pitfalls and scope of automatic methodologies.

## 2. Manual Harvesting

Famers have traditionally harvested using manual harvesting techniques [3].Manual harvesting is the fruit picking carried out with hands. It does not involve any major machines and improves the accuracy of product selection that is quality, mature and ripe. This is useful when we need to pick fruits multiple times in a season and avoids any mechanical harm to the original tree [4]. Its uncommon that 100% of the plants will have all ripe fruits and complete tree can be harvested for the full yield. Fruits that are utilized for fresh consumption can rely on manual harvesting methods. Fruits with long maturation period like orange, coconut, mango, papaya have been commonly picked manually. Manual harvesting is also utilized as a clean-up operation to collect leftover fruits after mechanical harvesting is complete [3]. Manual harvesting is done in different ways:

- Ladder and bag picking method –utilized for tall trees where fruits are located at height. Farmers utilize special ladder which is usually made up of two frames that keep balance neat and supports easy movement of the ladder. Platform and rod arrangements of ladder allow stability and mounting of bag units to store the harvested fruits. This method is useful for superior quality fruit harvesting but utilizes significant time in ladder movements and transition up-down.
- Poles and clippers method – utilized for selective fruit picking and has received recent popularity due to its low-cost equipment. It utilizes a telescopic boom which can be fixed to a height based on manual adjustments. Movable cutting blade or clippers are utilized using manual thrusting or using wire network. Individual fruits are cut and collected in the adjacent bag. This is useful for fruits that can get damaged if they fall on the ground like papaya, orange, mango, etc. This method also converts into shake and catch to improve the speed of the harvesting.
- Harvesting using cutting knives – this is useful for bush fruits and is very effective manual harvesting technique in terms of speed and safety of products. Orchids utilize movable/mounted collectors where labor use specialized cutting knifes to detach the products from mother trees and safely store. Cutting knifes are a common tool available with labors, unlike ladder and poles. Orchids for strawberries, grapes utilize this manual technique.
- Harvesting using digging tools – one common fruit grown underground is peanut, that has been traditionally harvested using digging tools. No other picking techniques are useful there. Although very specialized, digging tool-based harvesting is an effective, fast paced multi-stage harvesting method[5].

Here are some critical parameters to discuss manual fruit picking:

### 2.1. Cost

As discussed before, manual fruit harvesting is cheaper for single instances, but costly when added cumulatively over season/multiple seasons. [6] performed a survey of 15 harvesting companies in Florida region that were responsible for the 18% harvesting of total citrus production in the area. The average cost per box for harvesting in Florida area for sweet oranges, specialty citrus and grapefruit were \$3.28, \$4.46 and \$2.65 respectively. The cost for harvesting of specialty fruits were higher due to the caution and labor process required.

Labouré's had to utilize careful picking techniques to avoid damaging the thin and delicate skins of fruits like tangerines, tangelos, etc. This situation continues in Spain as manual harvesting is preferred for citrus fruit there as well. A considerable portion (29% and 43%) of total direct production cost for oranges and mandarins respectively went into harvesting in Andalucia [7]. Furthermore, Brazil also showed the total labor cost for harvesting of citrus accounted as 44% of the total production [8].

### 2.2. Efficiency

Manual harvesting methods are not efficient. Due to lack of mechanization, they involve repetitive practices that require more time and incur extra labor cost. [5] Common harvesting techniques like usage of ladder require constant going up and down to pick the fruits. They are collected at segregated locations for the ease and then transferred to central holding or packaging facility for further processing. Few cases have these post-picking activities contribute to more than 50% of total harvesting time [9]. There have been certain innovations that can potentially reduce the time for non-picking activities in total harvesting.

For example, multi-picker positioning platforms have been introduced to create a localized sub-unit of picking-to-collection of fruits and directly reduce the time with increased efficiency of non-picking activities. Several companies in US developed these platforms for citrus fruit harvesting in 1970s. However, the efficiency advantage from their use could not justify the cost of their purchase and maintenance. Additionally, these platforms were unable to significantly reduce this non-picking time, but provide incremental improvement [10].

### 2.3. Training-accuracy

Manual fruit picking is utilized due to its accuracy in selecting right product and reducing the wastage as well as damage to the mother tree. However, fruit picking requires specific instructions and training to the general-purpose labor available for the job. For example – there are different reasons of harvesting mangoes at different stages of their ripening cycle. The pickle mango needs mango to be cut from stem and the mango that needs to ripen during storage/transport for direct consumption needs a small part of stem to remain attached. There are specific instructions in the fruit harvesting of simple fruits, aggregate fruits and composite fruits. Additionally, instructions differ for fresh v/s dry fruits as well. If the wrong person is selected for the harvesting job, then the cost of training and loss of product can exceed more than $30K (oral communication). Additionally, its impact on labor safety is a critical element not to neglect. Summarizing, manual fruit picking is dependent on skilled labor and their availability[11].

### 2.4. Worker-safety

Manual harvesting is haunted by the lack of worker availability and issues related to worker safety. The repetitive tasks, lack of effective safety gear due to cost/availability, use of common risky harvesting techniques like ladder/poles make the worker-safety a critical issue in manual harvesting. Mechanical harvesting techniques take this advantage with minimum on-site worker requirements [12].

Here is a summary of benefits and pitfalls of manual harvesting:

**Advantages:**

- Fruit selection is precise considering ripening, maturity and size/shape or other attributes of the fruits.
- Fruit handling is smoother to reduce any machine damage to the product as well as tree.
- Single event of manual harvesting requires minimum cost, but its repeated usage can be expensive.

**Disadvantages:**

- Manual harvesting is limited by the availability of labors and is controlled by the demand-supply economic as well as political scenario of the market. Specifically developed countries face expensive labor cost for manual harvesting.
- Adding to above, manual harvesting requires extensive training to new labors due to crunch of skilled and specialized labors.
- It is a time-consuming process and requires repetition of picking-to-storage management cycles.

**Fig. 1.** Pepper (left), strawberry (middle), and fig (right) are harvested by hand.[13]

## 3. Mechanical Harvesting

Mechanical harvesting uses mechanical devices to harvest the produce on a large scale. Mechanical systems are designed to harvest a large scale of products in a single iteration during harvesting. This harvesting is fast and provides consistent results. Mechanical harvesting is common in grain harvesting where tractor or mower-based machine harvesters are utilized for efficient grain detachment, even primary processing as well like removal of husk. Fruit harvesting machines utilize practices like shaking the tree, chemical spray to loosen the ripe fruits, etc. It's important to select proper machine to harvest specific fruit to avoid damage. Mechanical harvesters cannot provide selection of fruits based on their size, shape, ripening. Manual filtration activities are required to perform sorting of produce after mechanical harvesting.

Mechanical harvesting can be utilized for fruits that have certain threshold for the mechanical damage. Fruits that are utilized for processing like use of tomato for ketchup, use of wine grapes for wineries, use of Apples for Jams, etc. can effectively utilize machine harvesting. Here superficial damage to the fruit does not impact its quality and can be directed for processing consumption effectively. Tree nuts are also well suited for mechanical harvesting considering the outer covering shell that can withstand machine techniques. Summarizing, fruits that stay strongly attached to the mother tree are prone to significant damage by using mechanical harvesting[14].

Regardless, the effectiveness of mechanical harvesting depends on the use of effective technique to keep consistent quality and increase the usable yield. The main advantage of mechanical harvesting is its efficiency to complete harvesting within short amount of time. For example, shaker techniques can remove fruits from complex tree environment within minutes compared to entire risk man oeuvres required for manual labors. This is why mechanical harvesting utilizes less labor, thus reducing labor management, hiring, training, etc. For example, the mechanical harvesting cost of sweet cherries per hector in US conditions was $0.72 per box compared to the manual harvesting cost of $1.79 per box [14].

Here are some examples of mechanical harvesters:

- Limb shaker: Limb Shaker mechanical harvesting is designed based on manual harvesting by shaking of tree limbs. Rather than using manual appendages that would require considerable force and multiple labor, Limb shaker utilizes machine that does the work. Limb shaker is portable and can even be hand held. There are common versions available where shakers are controlled remotely by an operator. Like other mechanical harvesters, limb shaker is utilized for plucking fruits that will be utilized for processing. Limb shakers work by shaking tree limbs in long strokes with low frequency. Due to such movement, they have potential to damage tree limbs and produce, with unripe fruit removal. The damage to fruits can be avoided by using safety nets and ground impact dampeners. Often, chemicals are utilized to loosen up the ripe fruits for easy catch. Fig. 2. Shows picture of limb shaker.

**Fig. 2.** Limb shaker example.[15]

- Canopy shaker: Unlike Limb shaker, Canopy shaker utilizes vibrating mechanism that impacts the small tines that attach to fruits or impact the fruits directly. Canopy shakers impact secondary branches so their high frequency vibrations release ripe fruits immediately. This means canopy shakers can useful when fruits are loosely bound to mother trees when ripe unlike fruits that have strong adherence. Canopy shakers also come in human propelled form and tractor led form. The orange harvesting in Florida is done using canopy shaker that utilizes 12 sets of free-floating tines, each 2 m long, that come out from a vertical axis. The yield of harvest success is dependent on placement depth of shaker in the tree, shaking frequency and fruit detachment force. Fig. 2. Shows picture of Canopy shaker.

- Trunk shaker: Trunk shakers up the ante a little by creating shaking mechanism for the entire tree than a branch or canopy. It also has hand-held and tractor mounted shakers with detachment rate improving from 57% to 72% for the later. Even trunk shaker efficiency ranges from 67% on large trees to 98% for small trees. For example, fruit detachment rates vary from 70% to 85% for mandarin v/s oranges in Spain [7]. Trunk shakers are useful for deciduous fruits that shed leaves annually. They cause defoliation due to high shaking frequency. Additionally, tree trunks can get damaged, to become prone to fungus. Fig. 4. Shows picture of trunk shaker.

- Air blast: One innovative method utilized for machine harvesting is air blast. Soft fruits like raspberries, strawberries can be harvested using air blast. A machine generated air blast is utilized to detach the fruit from tree. Machines oscillate the air blast to increase the efficiency of detachment. Air blast harvester performance depends on the complexity of tree, size and weight of the fruit, load of fruit on the tree and loosening of fruit after ripening.[18][19][20]

**Fig. 3.** Canopy shaker example.[16]

**Fig. 4.** Trunk shaker harvesting example[17] (Courtesy Feucht Obsttechnik GmbH Company)

Here are some critical parameters to discuss mechanical harvesting:

### 3.1. Cost

Machines reduce the overall cost of harvesting through mechanization and reduced dependency on labors. Considering the injuries and damage to the produce, it's important to select mechanical harvesting for specific orchids at optimal time of the season. Additional costs are laid to safeguard fruits from damage from falling to ground using safety nets or pads. Containers for fruit collection and harvesting tools need thorough cleaning to avoid any germ transfer. There is training cost involved to upskill operators on harvesting methods and ripening stages. In US conditions, the mechanical harvesting cost of sweet cherries per hector was $0.72 per box compared to the manual harvesting cost of $1.79 per box[7].

### 3.2. Efficiency

Mechanical harvesters require few minutes to few hours to complete the harvesting of fruits per tree. There are post-harvesting steps required to collect, clean and stores fruits. Due to defoliation, the true efficiency considers post-harvesting cleaning that can take more than 50% of the time [21].

Here is a summary of benefits and pitfalls of mechanical harvesting:

**Advantages:**

- It reduces the harvesting cost.
- It improves the harvesting turnaround time.
- It utilizes the labor workforce effectively for less repetitive and more cognitive work-items.
- Due to an increasing availability of equipment on loan/rent, mechanical harvesting has become scalable, flexible along with cost friendly as well.

**Disadvantages:**

- It does not offer a precise selection of product, based on its quality and maturity.
- Mechanical harvesting does not offer selective harvesting. It has potential to impact future yields from the mother tree.
- Mechanical harvesting is not useful for crops that take multiple yields in same season.
- The wastage of products and mother tree are higher during mechanical harvesting.
- Mechanical harvesting can be expensive for small farmlands. Farmers can get most benefits out based on their optimal usage of the mechanical instruments.

## 4. Automatic Harvesting

To further advance into using machines for harvesting, there has been recent developments in automatic harvesting using robots and mechanization of various decisions in the harvesting process. The decreasing availability of manual laborer's and increasing cost of harvesting requires an automatic solution to complete harvesting. The overall automation in harvesting processes has improved the nutrient optimization, ripening detections and the storage systems management/maintenance. The use of automation in fruit plucking has been limited considering the complexity of two underlying challenges – a) Fruit detection and localization in the complex natural environment and b) robot arm movement to reach the fruit and picking process [23,22].

For picking/harvesting process, there are numerous end effectors are utilized:

- Gripper: Among detection, harvesting and movement components of robot-based harvesting, prior two are most important. End effectors should facilitate easy detection and avoid damage to the produce/mother tree during harvesting. For detection, color camera can be the simplest mechanism to capture images and detect fruits suitable for harvesting. Grippers in combination with infinity rotational joint become a good end effector. Comparing them with scissor hand, they do not face the stem accuracy estimation problem to be put under the gap of blades, but rather rely on rotational movement for plucking. This way fruit can be harvested regardless of the direction of stem. Survey by [23,24,25] shows the effectiveness of Gripper mechanism for tomato harvesting.
- Vacuum: For harder fruits like apple, end effectors with vacuum mechanism can also be effective. [26] study shows the use of camera sensing system, robot hand with 3 degrees of freedom and a vacuum-based end effector. For effective harvesting, the control system enabled end effector to be in vicinity of fruit by not more than 2 cm of distance. Vacuum harvester was able to function in acceptable limits and remove fruits under lab experiments.

  Fruit detection is based on sensor or picture data analysis. The major intent is to be able to identify the fruit. Process goes through capturing image with camera/sensors, feature construction using masking, pre-processing to improve the image quality and removing noise, segmentation to create image clusters and classification into meaningful groups.

  Fruit detection approaches have been divided into two sections: location-based detection and shape-based detection. Here are brief details:

- Location based detection: Location detection enables end effector to reach fruit effectively. One common methodology used for location detection is the 3D point cloud generation, that is done using structure-from-motion (SFM) photogrammetry. Process has high accuracy with reduced number of false positives. However, SFM process is slow due to heavy processing time. SFM combined with instance segmentation can provide high 3D fruit detection precision.[27]

- Shape/color-based detection: Color based and contour based shape detections are a common segmentation technique. Circular Hough transform (CHT) help in detection of curvatures and differentiate between fruits v/s other tree features. RGB based segmentation, combined with depth filters and region growing provides multiple clusters that enable right digital representation and detection of the image. Shape detection algorithms can be universal to migrate from one fruit to another with minimum modifications and shape specific algorithms that allow detection of fruits with similar shapes. Physical optical filters have been utilized to improve the color intensity of the fruits and ease their shape detection.[28,29].

Currently fruit harvesting techniques from image thresholding, neural networks to deep learning are proposed / utilized [30,31, 32,33,34,35]. A few applications with AI (Artificial Intelligence), deep learning approach are mentioned in Table 1.

There are number of publications in autonomous harvesting increasing day by day. Paper [36,37,38] shows the uses of machine learning and artificial intelligence for correct detection. The papers for fruit harvesting employing active perception published since 2016 are evaluated in this systematic review. Every fruit and cultivar has unique qualities and characteristics that influence harvesting. An apple, for instance, is simple to grab and take off, whereas grape bunches must be handled carefully and cut by the stem. In Fig. 5 x-axis indicate the count of publication and on Y-axis indicate Fruit . It is obvious that the research on three cultivar types apple, pepper, and tomato has a major influence on the analysis that was conducted. It is common practice to grow tomatoes and peppers in greenhouses, according to the literature assessment. Additionally, the majority of studies on apple harvesting discuss detection methods rather than efficient harvesting. However, by literature review it concULcated that the interest in using robots to harvest various fruits has increased over the past few years[39].

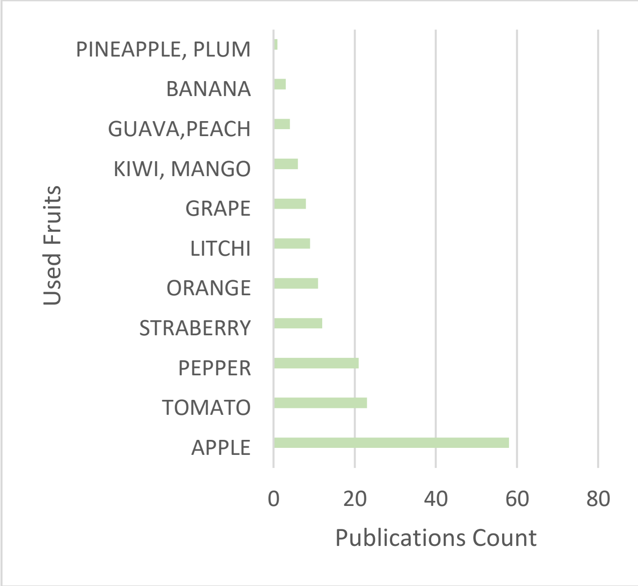


**Fig. 5.** Exploration of Autonomous Harvesting Across Different Fruit [39]

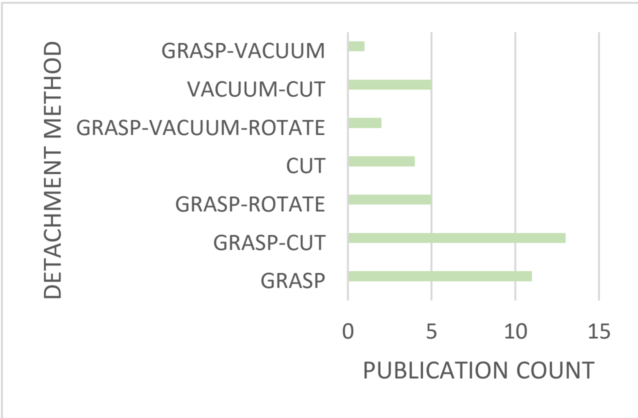


**Fig. 6.** Used detachment method by publications[40]

One of the most crucial aspects of autonomous harvesting after fruit selection is detachment technique. Cutting, vacuuming, rotating, and grabbing are some of the separation techniques. Various detaching techniques have been used singly or in combination. Fig. 6 displays every combination found in the literature review. It is reported that there are seven different combinations: (1) grip-cut, (2) grasp, (3) grasp-rotate, (4) cut, (5)

vacuum-grasp-rotate, (6) vacuum-cut, and (7) vacuum-grasp. Figure 13 illustrates the most typical detachment technique, which combines gripping and cutting. Grasping and cutting can ensure that the crop is secure and not harmed by excessive pulling when harvesting fruit[40].

**Table 1.** List of applications in automatic harvesting

| Crop | Machine intelligence method | Benefit / Challenges | Reference |
|---|---|---|---|
| Apple/Multi-fruit | It uses the AI perception that utilizes neural network to perceive the fruit the way human mind does. Vision algorithms are employed that process the digital image produced by sensors to convert it into machine interpretable form. | With the implementation of these algorithms in drones, we can customize the identification and plucking of various fruits and easily customize the system. | [41] |
| Multi-fruit | It uses multi-layered neural network technique, often marked as deep learning technique to solve for image classification and object detection with ease. | With vast instance of data and comprehensive image detection training, deep learning algorithms have ability to detect multiple fruits and even support fruit classification based on their size, colour, ripeness, etc. | [42] |
| Apple/Multi-fruit | It uses the AI perception algorithm to acquire, select, present and store sensory information the way human receptors do for smell, vision, touch, etc. | Achieved speed of detection, localization and plucking of fruits across multiple fruits. Author showcased the fruit plucking speed matching to 91.7% of human accuracy with the support of modelled canopy as the end effector. | [43],[44] |
| Strawberries | It uses semantic segmentation for the detection of single fruits, instance segmentations for delineating overlapping fruits using convolutional neural network for multiple layers. | Instance segmentation with CNN classifies fruit pixels separately to detect different fruits and allow plucking of soft fruits like strawberries delicately. | [45] |
| Strawberries | Method has a setup of 3 RGB camera that colour-based classification to wavelength signature of ripe fruits. | Provides plucking time of 4 sec, 70-95% of ripe fruits harvested for table-top farming technique. | [46] |

| | | | |
|---|---|---|---|
| Sweet paper | It uses subjective colour consistency for fruit detection and semantic segmentation using full convolutional network for stem detection. | This allows high signal to noise ratio in the outdoor complex environment for fruit detection and understanding angle of stem for effective plucking technique. | [47] |
| Yellow paper | It uses heuristic technique to make locally optimal choice to detect fruit using epsilon-greedy algorithm. | This reinformed learning algorithm needs less computational resources compared to exhaustive search and less labelled images. The performance is 91.5% of exhaustive search and resource requirement is 73% of the total iterations. | [48],[49] |
| Mangoes | It uses Mangonet, a deep convolutional neural network, specifically designed to detect mangoes in the complex real-world systems. It provides stable results in different illumination and real farm conditions. | Mangonet has provides F1 score of 0.844 and accuracy of 73.6% against fully convolutional networks. | [50] |
| Strawberries | It uses continuous and discrete steering angle from RGB input device to apply Visual Geometry Group, Oxford's Oxford net algorithm. | Deep convolutional neural network creates a complete learning strategy to adopt to real-world scenarios and different seasonal conditions. It provides the accuracy of 97.9% in Polytunnels test and 78.6% in Trails Making test. | [51] |
| Grapes | It uses Mobilenet that is a lightweight convolutional neural network that has low latency for mobile and embedded systems. | System had a F2 score of 0.9 in revolutions to achieve balance between convolutional requests and accuracy of detection. | [52] |
| Cirtrus fruits | It creates a map of image area and runs patch convolutional neural network using boundary lines to separately get results for each patch of image. | The minimum path for localization was 0.81, whereas the lateral and angular errors were 0.051 and 7.8 degrees respectively. | [53] |

| | | | |
|---|---|---|---|
| Vineyards | It uses Tensor processing unit for edge and combines the Mobilenet v1 and v2 to finalize a compatible compilation module under TensorFlow Lite. | In lack of global navigational satellite system, this can support speedy, accurate detection and plucking of vineyard produce in unstructured, tilted real-world vineyard environment. This provides 40 fruits per minute speed with overall precision ranging from 31.32% to 52.98% based on the selection of application between MobileNet v2 v/s tiny YOLO v3. | [54] |

In autonomous fruit harvesting arial applications are also in boom.. In addition to monitoring [56], surveillance of watering [57], weather [58], soil quality [59], maturity [60] and yield estimation [61], detection of diseases [62], and sprinkling operations [63], drones are widely utilized to evaluate crop properties [55] at the farm-scale. The use of drones in fruit picking and harvesting activities is the next significant step in the use of drones in crop management. Comparatively speaking, small drones could harm crop rows less than a robotic heavy truck[65].

Drones might theoretically be used to pick hard fruits like apples, pears, and oranges that grow on trees. Softer, slower-growing fruits like strawberries, which grow at an impractical altitude for the drone to reach, require gentler handling to avoid harm. While green vegetables need to be gently lifted from the ground and may be easily torn if picked from above by a drone, heavy crops cannot be gathered with the low payload required of a drone. Because of this, airborne harvesting is difficult and hence rare, but it is happening now.

Autonomous flying fruit-picking robots were introduced in 2019 by a cutting-edge startup called Tevel (Fig. 7) [64]. A two-finger cup-shaped gripper served as the end effector on the first prototype. A complete harvesting system was introduced in 2021 by the same team. Three-finger grippers were the suggested end effectors for picking apples; no other information or review was offered. The method was used with apples as well as with other fruits of a comparable size, like oranges and mangoes.

**Fig. 5.** aerial harvesting robot [63]

Here are some critical parameters to discuss automatic harvesting:

**4.1. Cost:**

Automatic harvesting utilizes camera-based systems. The cost of

camera increase based on the quality images, its ability to mount on robot end effector, etc. The robotic arm is a mechatronic instrument, where its development or purchase cost depends on the custom requirements like rotatory, cutting, sucking mechanisms. However, automatic harvesting provides long term benefit with one-time investment and small maintenance cost. It saves labor cost and removes dependence on market dynamics and labor shortages.

**4.2. Efficiency**

Automatic harvesters are useful to reduce the redundant labor wasteful processes and movement of instruments. Automatic harvesters work at higher operation speed and provide improved safety compared to labor intensive workplace. Automatic harvesting can be customized to include/exclude task variations and combine harvesting to collection to storage systems built under same mechanism. Automatic harvesters, however, have varying performance based on the complexity of the environment and require tweaking the algo-machine interaction for accurate fruit harvesting.

Here is a summary of benefits and pitfalls of automatic harvesting:

**Advantages**

- Automatic harvesting can reduce cost for large orchids with right plucking system, ripening identification, reducing harvesting wastage and automation of manual processes.
- It provides harvesting efficiency improvement using faster, accurate systems, easy to install & utilize solution, human less technical implementation.
- It provides solution to labor unavailability, especially solving for peak periods where demand reaches highs and farms face overall manpower reduction.

**Disadvantages**

- For small orchids, the initial cost of robot purchase, assembly and maintenance can outweigh the manual labor utilization.
- Robots can impact the perception of harvesting considering its reducing the dependence on manual Laboure's. Additionally, considering energy consumption of automatic systems, the adoption can be influenced emotionally.
- Robots are useful to carry out repetitive tasks and have been commonly utilized in manufacturing, packaging industries. Farming and fruit harvesting are considered to be crud environments and need quick decision making by analyzing multiple variables. On ground implementations would continue to require manual operators to support automatic systems.

## 5. Discussion

From pre-historic times, when hunters witnessed the cycle of plant growth and ability to sow, that laid to the start of agriculture and civilizations.

From a primary need of fruit generation agriculture has evolved into in full fledge industry as global population increases the need of modernization, mechanization, improved farm management techniques and combining engineering with bio chemistry has been the need of time.

Agriculture has seen green revolution that showed usage of technology to increase, produce and bring efficiency in agriculture. However the mechanization has been limited to man driven machines replacing traditional farm processes like planting, harvesting, spread of pesticides, etc.

usage of human less automation can bringing significant cost benefit as well as efficiency improvement in the repetitive, monotonous task of farming. Application of robots in fruit harvesting has shown promising results specifically when labor availability is diminishing. cost of labor is increasing and farmers are utilizing structured methods of farming so far, considerable research has been conducted with range of sensors, variety of end effector and a variety of computer vision techniques. to find solutions for fruit harvesting in the complex real world. many researchers are still engaged in discovering solutions for specific repetitive farming task and use cutting edge technologies to build the modern agriculture. on the other hand it's rare to see farm automation like robot or drone reaching commercial level and being utilize at scale. like any other industry automated harvesting faces same issue of low recognition rate, low speed of localization, low speed of operation as well as limited success in fruit harvesting.

The complexities of real field conditions, managing end effector movements, navigation of robotic hand, problems in parallel watch-grab-harvest operation and high hardware cost lead to low success rate.

to solve for these constraints researchers dividing the challenge into 3 sub problems. first fruit identification and characterization, second localization and guiding robot and third harvesting and returning produce to safe storage. many researchers have tackle the first problem effectively. remaining two require numours trial-fail-learn cycles to implement the guidance system for robot. there has been considerable technological advancement in robotic hands. however the complexity of real world fruit harvesting increases due to occlusions, soft and delicate produce, Varity of shape and sizes, variety of fruit orientations and uneven terrain. machine harvesting makes good strides in improving the efficiency. however lacks precision and causes damage to mother trees. considering this automated fruit harvesting remains a challenging space for researchers and requires sophisticated techniques to improve the accuracy from fruit identification to localization. considering the diversity of fruits in India the focus can be on orchids, mid to large size farm and fruit specific design of the product. a universal 'one size fits all solution will require considerable time, cost, researchers, and engineering magic in agriculture'.

## 6. Conclusion

A conclusion elaborate on the importance of the work or suggest applications and extensions. Considering the evolution and growing need of fruit harvesting, its important to bring technological alternatives to common fruit farming challenges like labor shortages, speed of harvesting, cost and storage requirement of this perishable produce. Paper shows the growth of fruit plucking techniques and current attempts to bringing artificial intelligence and computer vision. This paper traces the development of plucking methods from prehistoric times to the present. By qualitative research this study shows advantaged and disadvantages of past, present and future ideas of fruit harvesting technique. By quantitative study

Paper also describes efficiency and cost for fruit harvesting techniques.

Paper has distinct advantages and pitfalls of different machine learning algorithms along with their accuracy score in real world fruit harvesting scenarios. Regardless of availability of cheap camera sensors its usage in automatic or assisted fruit harvesting has not been generally popular. Due to real world difficulties there still lies considerable scope in bringing and improving automation solution in harvesting as well as other farm activity.

### Author contributions

**Madhura Shankarpure:** Quantitative Literature Review, detailed analysis of cost, Efficiency, Writing and Editing

**Dipti Patil:** Qualitative Field study, Guidance, Reviewing.

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