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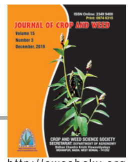

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Review Article

Use of shaking mechanism and robotic arm in fruit harvesting : A comprehensive review

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ABSTRACT

A broad overview of the various techniques of fruit harvesting in the field and greenhouse is presented in this paper. Fruits are harvested mechanically or by using a robotic arm which reduces labor requirement. Mechanical harvesting is not suitable for damage-prone fruits. The detachment of fruits by shaking the tree at trunk, limb, or canopy or by oscillation using air blast is considered as the mechanical harvesting system.The effect of shaking frequency and amplitude have been thoroughly discussed in this article. On the other hand, harvesting using a robotic arm is very much effective for high-value crops. The construction and working principles of various types of fruit harvesting robotic arms have been discussed along with their performance in terms of successful harvesting rate, execution time, etc. Grasping approaches for plucking fruits have been illustrated. Grippers with different mechanisms were reported with gripping efficiency. A significantly higher harvesting rate is obtained through mechanical harvesting over manual picking. The detachment of fruit by shaking mechanism has been implemented successfully with the highest fruit removal efficiency of 93.3%. The maximum picking rates of trunk shaking harvesters, canopy shakers, and manual pickers were found as 0.5 t h^{-1}, 10 t h^{-1}, and 25 t h^{-1}, respectively. A higher harvesting rate was reported in the planned architecture of fruit orchards. On the other hand, well-designed robotic arms were found to be very accurate (highest 94.2% accuracy) and with very low cycle time (lowest 4-5 seconds). In the field operations, environmental factors like vibration, dust, occlusions, lighting conditions, etc., affect the performance of robotic arms. Manual harvesting process is still a better option in terms of higher harvesting rate and lower harvesting time. Hopefully, these research gaps will be fulfilled soon and the robotic arm will emerge as a suitable substitute for the manual harvesting technique.

Keywords: Adaptive gripper, airblast, robotic arm, shaking mechanism, vacuum gripper

Agriculture and food play a major role in the economic, social, and individual status of many developed and developing countries. Innovation in mechanization and precision is bringing on various worldwide revolutions in the field of agriculture (Bachche, 2015). The rapidly increasing population of the world demands a large amount of quality food. In Asia, a shortage of agricultural workers and higher labor costs are serious problems nowadays. Even, the young generation doesn't show much interest in this profession. To solve this problem, a lot of researches are going on to implement mechanization and automation in various agricultural operation to replace manpower. Automation is being applied in greenhouses these days. Automatic machines and control systems are used in high-tech greenhouses to harvest fruits and vegetables. This saves harvesting energy consumption and labor cost (Schertz and Brown, 1968).

In mechanical harvesting systems, damage-resistant agricultural products like almond and olive, are removed in mass in harvesting season. This method includes limb shaking, canopy shaking, trunk shaking through mechanical vibration, and oscillation by the air blast. But the main drawback of this method is that quality and size selection cannot be possible and sometimes damage to the fruits and trees occurs to some extent (Li *et al*., 2011). But the delicate fruits like strawberries, oranges, or tomatoes cannot be harvested using this method. Because the fruits could be damaged by falling directly on the ground or by being hit by the branches. This will lead to the loss of quality and reduce market ability. Sometimes unripe, small, and immature fruits also get detached by this method (Coppock *et al*., 1969). Again, additional labor costs would be needed for collecting the dropped fruits from the ground after shaking.

In contrast, the manual method is highly time-consuming and involves human drudgery. In manual harvesting, the requirement of labor-power is large and labor charges are rising day by day. Automation can maintain productivity and reduce this huge labor requirement (Coppock and Hedden, 1968). Automation in the harvesting of fruits makes it faster and reduces the uncertainty of the availability of laborers during the harvesting seasons. The automatic harvesting systems enable farmers to harvest fruits from the trees efficiently with a very low harvesting cost (Schertz and Brown, 1968).

This review paper has been presented to describe existing techniques and ongoing researches for

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harvesting fruits. Most of the data regarding this are taken from various scientific and technical journals; the objective is to bring the latest information on the fruit harvesting techniques in one paper and to help young researchers with further innovations. Though some review papers were found, this paper is very updated and presented in a very concise way for better understanding.

Firstly, the harvesting functions and the crop factors for harvesting have been illustrated. Then, harvesting methods through mechanical shaking have been presented. The next portion contains a detailed discussion on the use of robotic arms for harvesting fruits in the field and greenhouse, plucking mechanism, various grippers, and performance of different robotic arms. Thereafter, a conclusion has been drawn.

Harvesting functions and crop factors

Proper care during harvesting and handling in the field directly influences the quality of products hence enhanced the selling price in the market. The total harvesting operation must be carried out keeping some factors and basic principles in mind. The maturity stages of fruits and vegetables in the commercial market depend on customers' consideration of physiological development. But this stage varies largely from variety to variety. The maturity stages of some common fruits are given in Table 1.

Table 1: Maturity index of fruits

Index	Examples
Elapsed days from full bloom to harvest	Apples, pears
Surface morphology and structure	Cuticle formation on grapes
Size	All fruits
Specific gravity	Cherries, watermelon
Shape	The angularity of banana fingers, Full cheeks of mangos
Firmness	Apples, pears, stone fruits
Tenderness	Peas
External color	All fruits
Internal color and structure	Formation of jelly-like material in tomato fruits Flesh color of some fruits
Sugar content	Apples, pears, stone fruits, grapes
Starch content	Apples, pears
Oil content	Avocados
Juice content	Citrus fruits
Internal ethylene concentration	Apples, pears
Acid content, sugar/acid ratio	Pomegranates, citrus, papaya, melons, kiwifruit
Astringency (tannin content)	Persimmons, dates

(Source: Bautista and Mabesa, 1977)

The primary function of harvesting is to detach fruits from stems. After detachment, the fruits are to be cleaned, selected, conveyed, and loaded to a conveyor. The order of functions is dependent on specific vegetables or fruits. In mechanical harvesting systems, generally, the product is sorted (by sorting device or manual sorting) after detaching it from a plant. But for manual harvesting, the selection function comes first (Srivastava *et al*., 1993). The detachment can be achieved by plucking (mainly by hand or robotic arm) or by shaking or by cutting the fruits or vegetables with a sharp tool.

Shaking mechanism for harvesting

Harvesting with vibratory or shaking motion to the branches of a plant is a widely used approach in mechanical harvesting. Vibration with suitable frequency and amplitude supplies enough kinetic energy to fruits and vegetables to be detached from the branches. While shaking or vibrating, the shaking tool forces act as an impact to the branches, causing the branches to accelerate or decelerate. This acceleration or deceleration reaches the fruits and it experiences a detachment force. When this force becomes more than attaching force, the fruit gets detached from the branch (Liu *et al*., 2018). The main two quality indicators for shaking mechanisms are removal efficiency and percentage of damage. Removal efficiency is the percentage of mechanically removed fruits. The removal force and quality are primarily determined by shaking frequency, amplitude, and duration (Loghavi *et al.*, 2010; Zhou *et al*., 2014). Fruit experiences twisting, bending, and shear forces while being vibrated. The capturing height determines the impact of fruit onto the catching surface and thus affects the fruit quality (He *et al*., 2017). Improper attachment of the shaking tool to the wrong location of the branch (limb or trunk) may be detrimental for the plant. Longitudinal and tangential stresses present there along with radial stress while vibrating (Moser, 1984).

Table 2: Frequencies and amplitudes for harvesting fruits

Harvested crop	Frequency (Hz)	Amplitude (mm)
Grapes	09–10/10–20	80–140
Apples	15–30	08–12
Apricots	15–30	08–12
Prunes	15–30	10–14
Almonds	15–30	08–12
Peaches	15–30	12–16
Olives	20–35	50–75
Cherries	10–20	15–60
Oranges	10–15	12–16
Strawberries	05–15	20–40
Tomatoes	05–10	30–50

(Source: Ruiz-Altisent et al., 2004)

Generally, mechanical harvesting techniques can be classified as canopy shaking, limb shaking, trunk shaking, and air shaking.

Canopy shaker

Gil Sierra (1990) used horizontal rods as vibrating tools to provide oscillatory motion and impact in a combination to detach wine grapes properly from their branches (8-16 rods with 1.2-1.8 m height). According to Peterson (1998a), the 'USDA Canopy Shaker' horizontal had a harvesting capacity of 7-9 trees per minute at a forward speed of 1.6–3.2 km h^{-1}. The removal efficiency of 80–90% was achieved for 'Valencia' fruit with a detachment force of 103-138N and a shaking frequency of 5 Hz (Peterson, 1998b). Whitney (1997) reported 25 t h^{-1} capacity of the USDA Canopy Shaker on higher-yielding 'Valencia' trees. Liu *et al*. (2018) developed a citrus canopy shaker harvester. The shaking tool was a nylon rod. In the field experiment, shaking tines were inserted into the tree canopy. Optimum shaking spot and frequency were found out in this experiment. The frequencies of vibration were chosen 1, 2, 3, 4, and 5 Hz. A frequency of more than 5 Hz was considered to be detrimental to plant damage. The limb was considered as a cantilever beam and the shaking spots were selected as 10, 20, and 30% of the limb from the branch end. Three shaking forces as 20, 30, and 40 N were chosen as the independent parameters. Shaking close to the junction of the stem and limb could cause maximum stress at the fruit end. The shaking spot and frequency affected the fruit removal time and removal efficiency significantly ($p < 0.01$). Fruit removal time was less in the case of higher frequency shaking.

Limb shaker

A mango harvester with an inertia-type shaking tool was developed by Parameswarakumar and Gupta (1991). A frequency of 11–13 Hz with 76–102 mm amplitude for 4 s was required for removal of mango with minimum tree damage, as they reported. Loghavi *et al*. (2010) developed a similar kind of handheld limb shaker powered with a single-cylinder gasoline engine. In the shaking test for the harvesting of Estahban edible fig, 10, 12, and 14 Hz frequency and three shaking amplitudes of 20, 32.5, and 45 mm were selected. A circular fruit catching frame was fabricated to reduce the damage to the fruit. Though 100% fruit removal was obtained at a higher shaking frequency (14 Hz), the unripe fruit removal percentage went beyond its permissible limit. 10 Hz frequency with 45 mm amplitude gave the best result in terms of higher mature fruit removal (93.33%) and the least unripe fruit removal percentage (9.44%). Torregrosa *et al*. (2014) analyzed the vibration motion of citrus fruits in slow motion for a better understanding of detachment parameters. They vibrated stem with 60-180 mm stroke length and 3-18 Hz. It was found that short strokes with a higher frequency required higher cycles which induced fatigue. Entire fruits were not detached at short strokes and low frequencies. So long strokes with fewer cycles were suggested for good detachment. Zhou *et al*. (2014) developed a handheld limb shaker with a hydraulic motor and slider-crank mechanism for harvesting cherry fruit and evaluated damage and removal efficiency on different excitation positions of the limb. The shaking frequency was controlled using a flow control valve.The fruit removal efficiency was found maximum at the excitation zone and it decreased gradually. De Kleine and Karkee(2015) developed a semi-automated mechanical fruit harvesting system with a mechanism dual-motor actuator (DMA). The end effector of the mechanism had infinitely variable rhythmic motions to detach fruit from limb. He *et al*. (2017) evaluated fruit removal efficiency (%), fruit collection efficiency (%), and fruit recovery efficiency (%) in a localized shake and catch harvesting system for various cultivars of apples. The limb shaker contains a reciprocating saw with a V-shape hook. The V-shape hook allowed the shaker to engage limbs with varying diameters. A new catching device consisted of a bounce buffer, a rolling buffer, and a collection area, was fabricated to minimize the speed and potential impact on apples was introduced in this study.

Trunk shaker

Whitney and Wheaton (1987) experimented on trunk shaker (FMC Model 4000) and found that harvested fruit was reduced by 10% than the yield of manually harvesting. The shaking time of 3-7 s per tree resulted in average fruit removal efficiency of 90%. Hedden *et al*. (1988) evaluated the harvesting performance of four trunk-shaking patterns (two linear and two multi-directional patterns) in 'Hamlin' and 'Valencia' oranges. A better linear shaking pattern resulted in better harvesting efficiency for a trunk-shaking olive harvester to achieve 80% removal efficiency.

Air shaker

In this method, a large fan was used to create a high-speed air-blast for shaking the tree canopy. Whitney (1973) evaluated the performance of ARECLA and FMC-3 air shaker on the 'Valencia' orange crop. A fruit removal rate of 2.9-4.1 t h^{-1} was obtained. A yield loss of 20-40% was found in the following year because of immature fruit removal. Sumner *et al.* (1979) used a three-fan air shaker to harvest 'Valencia' oranges. 90% of the mature fruits were harvested with a harvesting time of 1.5 trees per minute. The yield of this machine was 20% greater than that of the manually harvested trees. Hutton and Lill (1982) reported a fruit recovery rate above 80% with abscission chemicals on 'Late Valencia'oranges in a 3-year study.

Harvesting with the robotic arm

In the present trend, harvesting is carried out automatically with the helping of a robotic arm. A robotic with a fixed base is called a manipulator. A manipulator consists of a base, links and joints, end effector/gripper, wrist, device/actuator, controller, and different sensors. The links are the mechanical members used to transmit power, and two consecutive links are connected by a joint. Two types of joints are generally used in robots, linear joints, and rotary joints. A linear joint (produce pure linear or translational motion) may be of two types sliding joint (S) and prismatic joint (P). On the other hand, a rotary joint (which produces pure rotational motion) is of two types, namely, revolute joint (R) and twisting joint (T) (Pratihar, 2017).

While harvesting with a robotic arm, certain crop characteristics must be considered (Herck *et al*., 2020). For example,

- There should be a good amount of visible area of fruit and vegetables to be harvested
- The end effect of the robotic arm should reach the object easily. Generally, robotic arms with higher DOF have more reachability.
- The end effector/gripper should not grasp the object in such a manner so that the grasping point must be away from the stem and not be covered with any obstacles.
- The fruits and vegetables must be satisfactorily detached from the stem. The mechanism of detachment varies from variety to variety.
- A lot of vibration present in the field. So the robot must be robust enough to handle such disturbance factors.

Various robotic arms used for harvesting

Hayashi *et al*. (2010) developed a 3 DOF cylindrical manipulator to harvest strawberries in the greenhouse. A rotary actuator rotated the manipulator at a speed of 3600 s^{-1} and a linear actuator moved horizontally and vertically at a speed of 500 mms^{-1}. Zhao *et al*. (2011) developed a 5 DOF (PRRRP) apple harvesting robotic arm mounted on a mobile vehicle. All the rotary joints were actuated with servo motors. The last DOF was made flexible for easy movement of the gripper to reach the target. Zion *et al*. (2014) proposed a multi-arm robotic system for harvesting melons. Four 3 DOF cartesian manipulators were used in a rectangular frame. There were lateral belts for the individual manipulator. After harvesting, the melons were to be put on lateral belts and lateral belts moved the melons to a longitudinal conveyor which conveyed the melons to a platform behind.

Barth *et al.* (2016) used a Baxter robot with 7 degree of freedom arms with eye-in-hand coordination in a servo control system. Silwal *et al.* (2017) developed an apple harvester in Washington State University with a 6 DOF robotic arm with five rotational joints and one base prismatic joint. Bloch *et al.* (2018) used three types of 3 DOF robotic arms to investigate the effect of orchard architecture (training shape) on the quality of harvesting. Three types of robotic arms were articulated type (RRR), telescopic (RRP), and cartesian (PPP). Onishi *et al*. (2019) developed a deep learning-based automatic fruit harvesting robot. The arm had 6 DOF with a maximum reach of 50 mm. The weight and repeatability of the arm were 11 kg and ±0.1 mm. To reach the desired fruit location the joint angles were calculated using inverse kinematics.

Xiong *et al.* (2019a) developed a robotic arm with a special type of cable-driven gripper for harvesting strawberries in polytunnels. The whole assembly was on a mobile platform. The arm performed a harvesting task with the help of a suitable vision-based system in which ripe and reachable strawberries were selected as the target object. Williams *et al.* (2019) developed a robotic kiwifruit harvester consisting of four robotic arms.The degrees of freedom of the arm were three having three rotation joints and rotation of each joint was restricted to 90 in the software. Fruit localization and detection were achieved through a deep neural network and stereo matching technique in real-world lighting conditions. A novel gripper was designed especially for kiwifruit harvesting. A nylon cable was attached at the end of the end effector to the inside of the harvester cabinet to convey the kiwifruit after harvesting. Barnett *et al.* (2020) proposed multiple robot arms (cartesian) with a facility of task distribution in kiwifruit harvesting. The robot had three prismatic joints and linear movement along three axes with a rectangular workspace.

Various grippers with different types of grasping and plucking mechanisms

Grasping patterns and parameters

At normal conditions, fruits remain in equilibrium under the gravity and elastic forces of the peduncles. While harvesting, cutting the peduncle at a proper length is very important. Improper cutting not only damages that particular fruit but also affects the neighboring ones. The detachment force for removing the fruit from a branch is affected by detachment patterns and stem-branch characteristics (Li *et al*., 2016). Tension force, bending moment, and torsion moment are involved in a fruit detachment process (So *et al*., 2003). Gilman (2003) found that diameter had very less impact on the force required to separate codominant stems and the strength of branch attachment was independent of the angle of attachment. Axial tension was the most influential factor on detachment force in an orange orchard as reported by Alper and Foux (1976). Along with this, the angle of application of tension played a major role to contribute detachment force. Rumsey and Barnes (1970) stated that the detachment force decreased with an increase in the angle of application for orange and grapes. Fruit with longer peduncles showed a lower rate of detachment in their observations. Bu *et al.* (2020) experimented with four basic picking patterns, namely: vertical tension, horizontal pull, twisting, and bending in fruit detachment. The detachment forces in the horizontal pull-picking and vertical tension test were found in a range of 4.56–47.65 N and 27.33 to 32.85 N, respectively.

Mechanical bruises often occur while grasping by the gripper (Pascoal-Faria *et al*., 2016). Lewis *et al*. (2008) implemented a novel ultrasound technique in apples to set a threshold static stress value for avoiding damage during grasping. Apart from grasping force, bruises depend on other factors such as ripeness, fruit temperature, and the radius of curvature. Peak stress is higher at the smaller radius of contact and increases the chance for more bruising (Van Zeebroeck *et al*., 2007). Using the force, contact time, and viscoelastic properties as input parameters Zhang *et al*. (2018) established a plastic deformation model of tomato during grasping.

Li *et al.* (2016) experimented to understand the effects of the fruit detachment process under four different picking patterns (One manual and there with a robotic arm having three fingers). No detectable fruit bruising was observed in manual grasping. But all robotic picking patterns involved some damage due to bruising. A robotic picking pattern where three fingers were acting in a parallel direction to the stem-calyx axis of the fruit, showed the lowest grasping force and detachment angle among all three robotic patterns.

Gripper mechanisms and various types of grippers

A gripper is an end-effector of a robotic arm attached to the wrist of a manipulator in the form of a device used for grasping and holding an object. Depending on the type of object a gripper may be internal or external, single or double, hard or soft, and active or passive. There may be two approaches to grasp fruits. Either, grasp the fruit peduncle first and cut it, or, grasp the fruit body and cut the fruit peduncle. Though there is very little chance of fruit damage in the first approach, the occlusion by canopy makes the total process more complicated to find the cutting point of the peduncle (Bac *et al*., 2016). Gentle harvesting can be achieved by soft gripping with the help of vacuum grippers or adaptive grippers. It is developed in the form of an elastic cup that can be used to grasp parts. In a vacuum-gripper, grasping becomes possible due to a pressure difference inside and outside of the grasping cup. A vacuum can be maintained inside the cup using either a vacuum cup or a venture (Pratihar, 2017). On the other hand, adaptive grippers, influence by Fin Ray® Effect, have flexible soft fingers that can adapt the shape of the object it is grasping. The mechanism is based on the physiology of fish fins.When force is applied on the finger side, it gets bent. Base and tip deform toward the applied load. The force bends the sides of the structure and deforms the base and tips toward the load. The crossbeams have been kept angled to the base to create a preferred direction of bending and minimize deformation force (Crooks *et al*., 2016).

The ability of the gripper to harvest depends on its design. Sometimes end effectors are too big to penetrate through the obstacles and cover the crop and properly grasp a fruit. So the geometry of the orchard and physical properties of fruits and vegetables must be taken into considerations while designing a gripper (Bac *et al*., 2016).

Liu *et al*. (2007) developed a special type of end-effector for harvesting spherical fruits. It was a double-finger gripper and driven by a Maxon DC servo motor. Rubber pads were attached to the inner sides of fingers and the distance sensor, proximity sensor, and force sensor were mounted. Instead of using scissors or cutting tools, a laser cutting technique with a laser unit and a focusing lens were adopted. A suction pad was also there for grasping a single fruit by vacuum from a cluster. Baetan *et al*. (2008) introduced a vacuum suction-based gripper in Autonomous Fruit Picking Machine (AFPM). The gripper consisted of a flexible silicone funnel with a camera mounted inside. A minimum diameter of 10.5 cm was found to be suitable for the funnel. The central position of the camera inside the gripper simplified the coordinate transformation from the image to the robot. Bulanon and Kataoka (2010) developed a gripper consisted of a wrist and peduncle holder for an apple harvesting robot. The opening and closing of the peduncle holder and the rotation of the wrist were actuated by a DC motor and a stepper motor, respectively. Hayashi *et al*. (2010) developed a gripper having two fingers, a suction device, and a photoelectric sensor to check whether the fruit has been picked or not. The shape of one finger was like a cutter. Picking operations were of two types; suction picking and no-suction picking. According to the biological characteristic of fruits, Zhao *et al*. (2011) developed a spoon-shaped gripper with an electric cutting device for harvesting apples. A position sensor, a vision sensor, a pressure sensor, and a collision sensor were attached to the end effector for intelligent sensibility to the complex environment. Font *et al*. (2014) proposed a gripper tool in which two upper fingers were moving to grab the fruit and two lower fingers were stationary to hold the fruit. This mechanism reduced stress on the fruit surface by minimizing the pressure for grabbing. Silwal *et al*. (2017) developed an under-actuated gripper that incorporated a mechanical feature called passive compliance for harvesting apples at Washington State University. It consisted of three high-strength tendon-driven fingers of two links each of them and three actuators. Rubber pads were attached to the finger and three distal joints were passively compliant flexure. The out-of-plane compliance of this flexure was advantageous in minimizing damage during unintended collisions and increasing grasp robustness to error (Dollar and Howe, 2010). Xiong *et al*. (2019a) developed a gripper with cable-driven six fingers (three active and three passive) for harvesting strawberries. The six fingers could form a closed ring by opening simultaneously and swallowed a strawberry from below. Two curved blades were mounted on two counter-rotating gears and rotated a servo motor. The attachment of the punnet was checked by one IR sensor mounted under the front side clamps. Williams *et al.* (2019) fabricated a gripper for harvesting kiwifruits which produced the rotation using an asymmetrical four-bar linkage. Silicon was molded over the fingers. Air pockets in silicon allow it to conform to the shape of the kiwifruit while grasping thus reduce bruising. Clasping and rotation action was performed with a pneumatic cylinder with a pressure of 400 kPa. Mu *et al.* (2020) developed a gripper with bionic fingers considering the physical properties of kiwifruits.The other components of that gripper were a fiber sensor, a Hall-effect position sensor, a pressure sensor, and a stepper motor. A fiber sensor was used to detect the kiwifruit into the gripper. The upward and downward movements were performed with a stepper motor.

Performance of robotic arms

Bac *et al*. (2014) reported eight performance indicators in their review. Those are fruit detachment success (%), false-positive fruit detection (%), localization success (%), harvest success (%), cycle time (s), damage rate (%), number of fruit evaluated in a test, and Detachment attempt ratio. For performing well, a robot should fulfill the following requirements: it must be economically feasible, technically capable of performing the task, match the logistics processes, must be safe, and must be accepted by consumers. The end effector developed by Bulanon and Kataoka (2010) showed a 90.9% success rate. Barnett *et al*. (2020) investigated on assumption for task partitioning is kiwifruits harvesting and proposed a harvesting scheduler to optimize task completion time. Indivisibility of fruits and fruit cluster growing style was the main reason behind the deviation from the approximation. Mu *et al*. (2020) mentioned that the robotic arm they developed was slower than a human with a success rate of 94.2% and an average cycle time of 4-5 seconds per kiwifruit. Williams *et al.* (2019) observed 'Grip failure', 'Knocked off', 'Obstacle', and 'Drops' phenomena for kiwifruit picking failure with an average cycle time of 5.5 seconds per fruit. Total 1456 kiwifruits were harvested with a 51.0% harvest rate, 24.6% were lost, and 24.5% remained.

Baetan *et al.* (2008) reported that Autonomous Fruit Picking Machine showed 80% harvesting efficiency with an average cycle time of 8 to 10 seconds per apple. Hayashi *et al*. (2010) obtained an overall successful harvesting rate of 41.3% and 34.9% in suction picking and no-suction picking, respectively. The time to pick the fruit and place it on the tray was measured as 11.5 seconds. A total cycle time of 7.6 seconds was required to harvest a single apple, as reported by Silwal *et al.*(2017). Their robotic arm could harvest 127 apples out of 150, resulting in a picking efficiency of 84.6%. The misses were due to positional error, poorly thinned branch, obstruction, sticking of previous fruit in the end effector, and incomplete detachment. This execution time was less than all the robotic arms previously stated but greater than the strawberry harvesting robot of 7.5 seconds (Xiong *et al*., 2019a). Before the field test, Xiong *et al.* (2019b) conducted a precision test and system localization accuracy in the indoor environment. The mean of absolute accuracy was 9.8mm and the mean of repetition precision was 4.6 mm which was higher in the field due to the complex environment.

In this paper, a broad overview of the various techniques for fruit and vegetable harvesting in fields and greenhouse are presented. Summing up all these, it can be concluded that, a significantly higher harvesting rate is obtained through mechanical harvesting over manual picking. The detachment of fruit by shaking mechanism has been implemented successfully with the highest fruit removal efficiency of 93.3%. Shaking frequencies, amplitudes, force, and location were set as independent parameters to achieve higher ripe fruit removal efficiency and minimize fruit damage and unripe fruit removal. The maximum picking rates of trunk shaking harvesters, canopy shakers, and manual pickers were found as 0.5 t h^{-1}, 10 t h^{-1}, and 25 t h^{-1}, respectively.Hence, 20–50 manual pickers can be replaced by mechanical harvesters.The use of various abscission chemicals accelerated the fruit removal process significantly, hence increased productivity. But all these shaking mechanism techniques work well in the planned orchard pattern. To achieve the higher fruit removal rate at minimum power requirement, the fruit orchards must be planted in such a way that the shaking elements can cover a maximum fruit covering area with a minimum forward movement of the harvester.

The introduction of robotic arms and automation for harvesting high-value crops has added new importance to fruit harvesting techniques. A well-designed robotic arm harvest fruits very accurately (highest 94.2%) and with very low cycle time (lowest 4-5 seconds). For successful harvesting, the most suitable grasping pattern must be studied for the target fruit. The damage and bruising on the fruit surface were avoided by using an adaptive gripper or by using any bionic material on the fingers of the end effectors. But, the maximum application of robotic arms is limited in greenhouses. In the field operations, environmental factors like vibration, dust, etc. affect the performance of robotic arms. Occlusions, light conditions are the main constraints for a fruit detection system that drastically reduce the harvesting rate. Due to the presence of costly sensors and precise actuators, the price of the robotic arm is very high and the overall operation cost is higher than the manual harvesting method. After so many researches the harvesting rate and accuracy of robotic arms have not reached a satisfying level. Time to harvest a single fruit is much higher than manual harvesting and fruit removal efficiency is also less. Hopefully, more intense research will be carried out in this area and the robotic arm will emerge as a suitable substitute for manual harvesting technique without any drawback.

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