



Artificial Intelligence Robotics Technologies for Harvesting Horticultural Crops: An Alternative Management Approach

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Abstract: The horticulture sector is very important in the agricultural industry of the Indian economy. The sector has huge potential to make a significant contribution to agricultural exports, but product quality is often a debatable issue in global markets. Global production of fruit has been growing rapidly, leading to increased competition in export markets. The global fruit industry can increase its competitiveness by adopting more effective fruit production and competent harvesting systems. Fruit production for the fresh market accounts for 60 % of the total labour requirement. Fruit harvesting is a seasonal activity and skilled labour in harvesting on time is quite problematic. Many farmers are concerned about the fact that there is uncertainty and a shortage enough labour during the peak season of harvesting. Most processes are done manually using traditional tools, increasing the total cost of production, and a decrease in net income for farmers. Therefore, there is a need to adopt the proper technologies to ensure that apple growers get benefits. One solution to these problems is AI robotic technologies capable of meeting complex tasks and having the potential to modernize the horticulture sector in the world. The goal of this paper is to provide an overview of the global growth and current status of development and scope of robotics in horticulture crops based mainly on literature established in several countries in recent years.

Keywords: Robotics fruit harvesting, Robotic picking, Atomization, Apple harvest, Fruit sensors, Horticulture

The Indian agriculture sector is developing enthusiastically day by day. Horticulture has been an emerging sector in agriculture and is increasingly recognized as a sunrise sector accounting for 90% of the total horticulture production in the country (Herrick 2017). Horticulture is increasingly recognized as a sunrise sector, owing to its potential to raise farm income, provide livelihood security and earn foreign exchange through export as shown in Figure 1. The diverse agro-climatic conditions and rich diversity in crops and genetic resources enable India to produce a wide range of horticultural crops, which consists of crops like vegetables, fruits, flowers, mushrooms, tuber crops, spices, plantation, aromatic, and medicinal plants. The horticulture sector encompasses a wide range of crops like fruits, vegetables, flowers, spices, and plantation crops like coconut, beverages like tea and coffee, and some medicinal and aromatic plants. Statistics provided by the National Horticulture Development Board indicate that, by accounting for 13% of the global production of fruits and 21% of vegetables, India is the second largest producer, after China, in both the commodity groups (Horticultural Statistics at a Glance 2021, Anonymous 2021). State-wise production of fruit crops is shown in Table 1. In recent years, horticulture has made significant progress in terms of increased area and production under various crops, increased productivity, crop diversification, technological interventions for production, and post-harvest and forward association through value

addition and marketing. As per the report, the total horticulture production in the country is estimated to be 313.85 million tonnes which is 0.69% higher than the horticulture production of 311.71 million tonnes in 2017-18. The area under horticulture crops has increased to 25.49 million hectares in 2018-19 from 25.43 million hectares in 2017-18. The increasing population and the mindset of adopting a healthy lifestyle have increased the demand for nutritional requirements in people, which provides vast chances for sustaining a large number of agro-based industries which creates substantial employment chances.

The horticulture sector has the potential to generate multiple sources of income, thereby boosting the economic growth of a country. Horticulture can be undertaken as market-driven cultivation of vegetables, fruits, and flowers, as eco-tourism, as therapeutic medicinal plant harvesting, and as a part of multiple farming to complement the main source of income. In tune with the emerging demands, India brought forth several technology and policy initiatives for promoting horticulture. The most important among them is the newer technology packages spanning from production to post-harvest (Anonymous 2019a). Protected cultivation, precision technologies including automation, and usage of biotechnology are some of the examples in this direction. Also, newer initiatives were made in the sphere of infrastructure development including cold storage, quality assurance, and streamlining and handholding to participate

in the export markets. Further, the Government has facilitated the emergence of newer institutional mechanisms to strengthen vertical and horizontal linkages through contract farming. Another significant dimension is to capitalize on the power of collectives. The formation of Farmer Producer Companies that could bring about the sea change in the input and service delivery systems is promoted. Evidence suggests that the net return in horticultural crops is higher than in other crops. The government of India has proposed to double farmers' income by the year 2025. It is increasingly being recognized that horticulture will remain an integral component of the strategy to achieve this goal.

The mechanization of fruit harvesting, especially those assigned to fresh or new markets, is extremely needed in almost all horticultural countries because of the low seasonal labour service in many countries. Some fruit-harvesting technologies are designed particularly for processing purposes only with limitations in their use for soft and fresh fruits because the fruit is susceptible to mechanical damage during mechanical harvesting (Anonymous 2019b). The alternative to modern mechanical harvesting systems, very superior but much more ambitious in terms of fruit quality, is an automated robotic system for fruit harvesting or picking. Robots can work well in a well-designed or controlled environment in which the direction and location of the target are very well known, or the object can be placed in the right place and desired direction. The detailed representation of the conventional arrangement and attributes associated with a harvesting robot that enable these machines to efficiently perform their tasks in the field is shown in Figure 2.

But nowadays, in the scientifically and technologically advanced environment, robotic systems or automated machines are used in unusual places or non-traditional zones, where the environment is used in optically guided warfare, medical robots, and agricultural robots (Kumar and Bector 2022). Currently, the Center of attraction and attention of much research on robotic fruit harvesting is the design of a harvesting system that copies the accuracy of a human harvester while reducing the labour requirements and increasing the efficiency of operations of a purely mechanical harvester. The comparison between traditional and modern automated harvesting methods is shown in Figure 3, which helps to gain insights into the various aspects of both traditional and modern automated harvesting, including efficiency, cost-effectiveness, and environmental impact. The classic design of a robotic fruit collector consists of the visual system of fruit detection, the stimulus to move towards fruit, and the end effector for fruit plucking and harvesting. Connecting the fruit detection algorithm to an automatic

harvester is an important part of the vision-based robotic fruit harvester. The idea is to extract information from the vision-based system about the spotted fruit and turn this information into instructions to direct the automated system to the right situation and to make harvesting a reality (Patel and George 2012).

The challenge of developing a cost-effective robotic system for fruit picking has been taken up by researchers at several places in the world. The major problems that have to be solved with a robotic picking system are recognizing and locating the fruit and detaching it according to prescribed criteria, without damaging either the fruit or the tree. In addition, the robotic system needs to be economically sound to warrant its use as an alternative method over manual methods. Researchers in several places around the world face the challenge of developing a more efficient robotic fruit collection system. The main issues to be solved using an automated collection system are the recognition, detection, and distribution of fruit according to established criteria without harming fruit or tree (Fu et al 2020). In the nineties of the 20th century, the new improved mechanical technologies in harvesting, achievements in computer interference, image interpreting technologies, and developments in tree design and fruit processing systems led to the development of a new generation of robotics in harvesting. Such technologies were more suitable and effective for fresh fruits, with higher yields and minimum damage. The major contributors to the development of such technologies were Europe, the United States, and Japan.

METHODS OF ROBOTIC HARVESTING

Two types of harvesting are used by horticultural practitioners to decrease the overhead output of horticulture from labour costs:

Selective harvesting: This is a selective method of harvesting by the robotic systems that use robotic manipulators equipped with an end-effector for grasping the fruits. They are usually installed on a mobile platform with machine vision technology for vision and the end-effector selectively separates mature fruit (Bac et al 2014) as shown in Figure 4 and 5. Since robotic systems can combine machine efficiency with long-term goal line (Shevfelt et al 2014), an automated harvesting technique is thought to have the potential to completely substitute the human pickers (Sanders 2005). Therefore, this method of selective harvesting has received widespread attention from both academia and industrial sectors and emerged as the ideal method of harvesting horticultural crops among fruit growers. The rapid development in artificial intelligence (AI) and robotics technologies has paved the way for commercial automated techniques for selective harvesting.

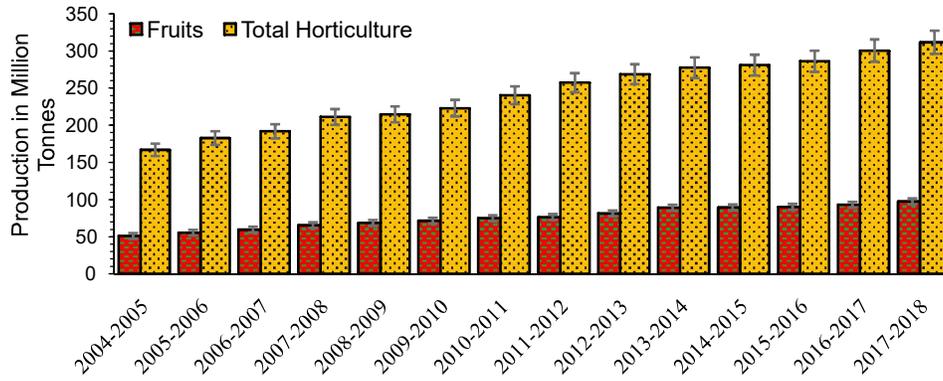


Fig. 1. Increasing trend in the horticulture sector of India (Anon 2020a)

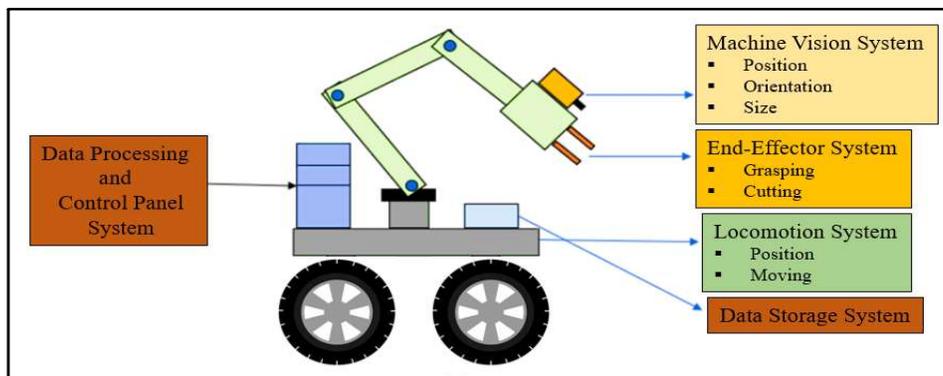


Fig. 2. Standard design and elements of a harvesting robot

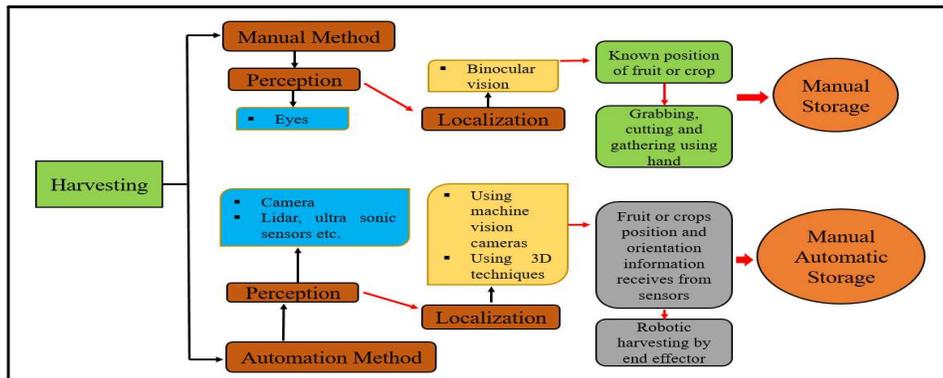


Fig. 3. Manual Vs Automated Harvesting



Fig. 4. Selective harvesting of apples with vision technology and end-effector manipulator

Bulk harvesting: The bulk harvesting method is based on the principle of using oscillation or vibration force on fruit trees to force the fruits from the trees (Mehta 2016) as shown in Figure 6. This type of harvesting method is implemented by many apples and cherries fruit growers (De Kleine and Karkee 2015, Zhou et al 2016). Although large-scale bulk harvesting systems are highly efficient (Sola-Guirado et al 2020), there are significant drawbacks. Farmers have expressed concern about extreme damage to canopies and fruit caused by mechanisms (Moseley et al 2012). The research studies to reduce bulk harvest damage remains active as fruit spoilage affects its market acceptance (Pu et al 2018, Wang et al 2019). Another big disadvantage of the bulk harvesting method is that the quality of the harvested fruits can change dramatically since less mature fruits are also harvested with mature fruits. The coordination of fruit and

vegetable maturity rates throughout the entire field is not a trivial job, and under a huge harvest scheme, harvest time can be based on minimizing the losses because of collecting immature and over-mature fruits during harvesting.

Robotic Harvesting Technologies for Horticulture Crops

Robots in the horticultural sector are widely utilized in harvesting, drone spraying, and field monitoring, sorting, grading, and packing of final horticultural produce, nurseries, and greenhouses to some extent. Several robots are already being designed for fruit cultivation as well. These AI robots can perform many heavy tasks and repetitive work with good efficiency in no time without any tiredness.

Fruit recognition, end-effector, and detachment: The first step in automated robotic harvesting is to spot the fruits and estimate their 3D location in the canopy of the tree so that the end effector can grasp the target fruit and separate it from the tree. Extensive research studies on the detection of fruits and obstacles using precise features such as shape, colour, edge, size, and texture, including different thresholds and classification techniques such as neural networks and Bayesian classifiers (Silwalet al 2014, Tabb et al 2006). However, these technologies based on the precise feature techniques, have limited success due to issues such as clogging, fruit gathering, unstructured, variable lighting conditions, various uncertainty conditions, and crop and canopy variability. To meet the challenge of fruit gathering, the convex hull technique is being used for the identification of individual citrus fruits and their center in the images with overlapping bunches of fruits with an assumption that the shape of the fruit is round in images (Changhui et al 2017). This is particularly useful when dealing with images where multiple fruits are closely packed together, making it difficult to distinguish between them. The convex hull technique helps in accurately identifying and locating each fruit's center, which is essential for various applications such as fruit grading, yield estimation, and quality assessment. Similarly, Wang et al (2017) developed an image enhancement technology that involved the Retinex principle and wave conversion to reduce problems related to fruit identification under changing lighting conditions.

Approaching the fruit is a key step in the robot's harvest, which mainly involves determining the optimal path and shifting the provincial final end-effector to the target fruit to complete the separation of the fruit from the tree. Approaching the fruit with visual surveying involves frequently identifying the fruit and changing its position using a recent end-effector based on the imaging system, as well as changing the position of the manipulator's joint (Mu et al 2020). An alternative to visual surveying is the use of a universal camera system, installed in a fixed position for

Table 1. State-wise production of fruit crops in India

States/UTs	Area ('000 ha)	Production ('000 ha)
Andra Pradesh	718.91	1761.67
Arunachal Pradesh	48.14	125.84
Assam	167.2	2518.89
Bihar	313.95	4384.46
Chhattisgarh	225.24	2580.31
Gujarat	433.79	9927.26
Haryana	67.28	712.02
Himachal Pradesh	230.852	571.739
Jammu & Kashmir	345.39	2564.27
Jharkhand	105.39	1111.96
Karnataka	395.55	6567.293
Kerala	321.36	1885.97
Madhya Pradesh	357.01	7464.97
Maharashtra	756.97	10822.77
Manipur	46.74	451.23
Meghalaya	35.75	331.67
Mizoram	62.91	339.18
Nagaland	33.94	315.34
Odisha	337.29	2361.13
Punjab	94.8	2001.69
Rajasthan	62.35	919.9
Sikkim	19.54	55.45
Tamil Nadu	293.97	5767.95
Telangana	175.9	2034.29
Tripura	53.702	555.473
Uttar Pradesh	480.53	10651.26
Uttarakhand	178.8	670.63
West Bengal	266.33	3829.85

capturing the images at the beginning of several harvest cycles. Next, the fruit condition of all fruits in the field of view or the given working space at the beginning of the harvest cycle is assessed. Once the live position of fruits and end-effector is assessed, the reverse kinematics is used for estimation of the new position of all robotic manipulator joints to finally move the end-effector to the chosen final position and direction (Fig. 7). Among the challenges facing this technology are accurate detection and detection of fruit from the beginning, and correct calibration between cameras coordinates and processor coordinates so that the end-effector can accurately reach the fruit.

A variety of end-effector techniques are used to harvest the fruit. One of the techniques is to isolate fruits using a mechanical end-effector with hands and fingers like humans. A soft Palm is used to prevent the fruits from being damaged. The fingers of the end-effectors of the robotic harvesters are designed with a hollow space finger from the inside and have a wrinkled surface on the outside. When the hollow space of the finger area is filled with air, the fingers approach the target fruit as the compressed air extends beyond the curved surface. This type of hollow finger can work faster than an electric or motor-operated manipulator (Figure 8). In addition, the soft hand provides a degree of cushion for the separated fruit. In general, however, these fingers are thicker than traditional fingers, making it difficult to harvest tightly packed fruits or fruits in groups (Shintkek et al 2018).

Another variety of end-effectors uses scissors types that cut the stem off to separate the fruit. However, it is acknowledged that the detection and location determination of stems for cutting purposes with scissors-type end-effectors is an extremely challenging task. To solve this problem, the cup-shaped scissors closed around the fruit can be used to cut the stem regardless of its position (Li et al 2011). This type of technique is more appropriate for fruit types with long stems. Different designs are used in mechanical hands, including a different number of fingers and actuators to control the fingers. One way to fit the finger is electric motors that carry each generation within reach, which requires multiple actuators in one hand, making them relatively slower, more complex, and more expensive. Another way is to use a tandem design, in which a single central motor pushes the fingers with a cable so that the hand can remain close to the target fruit to confirm the shape and size of the fruit when the desired quantity of force is applied in the cable (Davidson et al 2016).

Most of the technologies use one or two actuators which are either pneumatic or electric, whereas the number of actuators varies from a maximum of up to four in the current robotic harvesting technologies for the detachment of fruits.

The choice of manipulative degrees of freedom plays an important role in harvesting processes. The ergonomics of different fruits are different. Seven out of 39 robotic processor technologies use electric actuators. Electric servo motors and stepper motors are used to process places with low weight and load. Hydraulic and pneumatic actuators are used for heavy payloads because of their high power-to-weight ratio. The breakdown of actuators used in the robotic harvesting technologies is shown in Figure 9.

Deep learning methods based on the artificial neural network: Deep learning has been successfully used to address various fruit recognition challenges in recent years. These methods based on artificial neural networks have been extensively studied and explored. With a multi-layered future, deep learning methods can form more high-level traits. Both low-level and high-level functions can be analysed and used to reveal the end goal. The deep learning method was used to detect and localize mangoes (Stein et al 2016). Similarly, Chen et al (2017) detected and counted oranges and apples with a fully convolutional neural network (F-CNN). Among many types of deep learning techniques, convolution neural network (CNN) is a more sophisticated method involving convolution and back dissemination to extract and capture the target goal (Fig. 10), thus significantly improving the accuracy and generalization of the recognition algorithm (Koirala 2019).

Depth images taken by the RGB-D camera can be used to detect the fruit. Fruit spotting in RGB images can be affected by changes in ambient lighting, maturity status, and uncertain background structures. RGB and depth images were integrated to detect kiwi fruit, and a 3% higher recognition rate was documented (Sa et al 2016). Researchers are working to use multimedia sensors and multiple images to detect fruit in complex orchard environments. Even though, these deep learning techniques and methods can be employed in various types of raw data, such as infrared images, depth images, RGB images, or various even combinations of them, to achieve high accuracy in fruit detection, the algorithm training requires a long amount of quality time as well as a huge number of raw images with labelling.

Robotic Technologies for Management of Orchards

In horticulture, robots are widely used in harvesting, field surveillance, drone spraying, grading, sorting, and packaging of horticultural products, greenhouses, and nurseries. Robotics Plus is working on versatile Orchard AI-Robotics projects. The objective of the project is to automate the fruit harvesting and pollination of apples and kiwi fruits by developing a centralized system in which other modules can be supplemented for various purposes such as spraying,

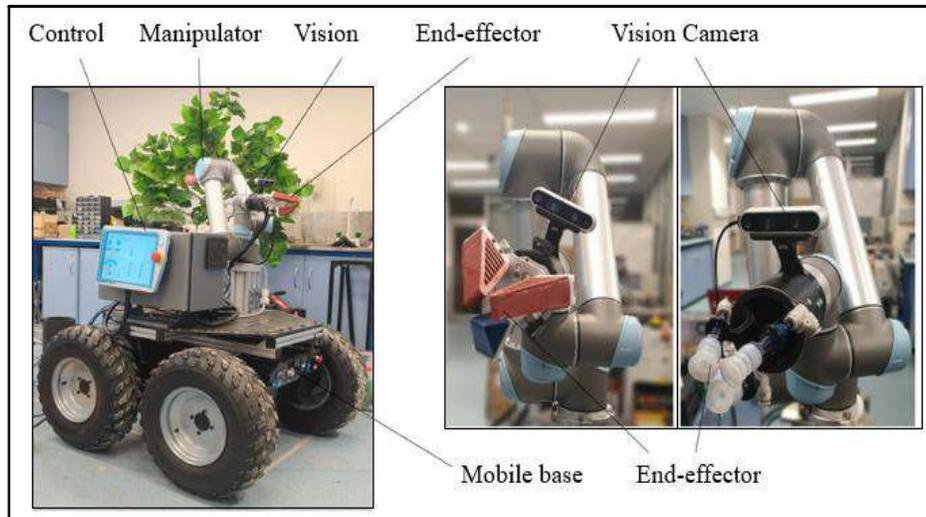


Fig. 5. Robotic harvesting system with vision sensors and different designs of end-effector



Fig. 6. Bulk harvesting method using mechanical tree shaker



Fig. 7. Robotic harvesting with end-effector installed with universal camera

pollination process, and fruit harvesting. A lot of research is also going on greenhouse-grown horticultural as well. Many robots have been developed for the harvesting of tomatoes and several crop functions such as leaf cutting and pollination (Charles 2018). Methods are also being developed that can predict the harvest and can measure the yield. All these data and measurement generators need to be able to manage their crops as effectively as possible in the greenhouse. A large number of companies around the world are investing in this aspect. Researchers have also developed mobile robots that use artificial intelligence to assess crop conditions such as almonds and apple orchards. Robots use artificial intelligence to evaluate the size of the canopy, which is directly related to crops which can be compared with the historical data to estimate flower and fruit concentrations. Therefore, it can help in quick counting of the pre-harvested fruits and anticipating the yield to be harvested. The various types of harvesting robotics technologies all over the world for harvesting several types of crops are shown in Figure 11.

It is recommended to use robotic conveyors to carry out automated harvesting with a minimum of seasonal staff, to transport empty or fruit containers to and from the workplace. An efficient automated bus requires i) autonomous navigation to have a basic function; ii) intelligent management within the orchard; and iii) container handling. Various types of harvesters currently being used for collection and transportation are shown in Figure 12. Fruit containers used in the Pacific Northwest region of the United States are typically designed to hold about 400 kilograms of fruit during harvesting for transportation, and storage. Therefore, the two basic requirements of robotic container carriers are the ability to handle a load of up to 500 kilograms and the effective movement within the orchard environment (Ye et al 2017). Current robotic technology has been able to meet this requirement by providing a self-propelled automated conveyor system for autonomous transport boxes (Hamner et al 2010).

The robot bin is involved in the navigation functions of carriers must guide the container holder with an empty pot to the tree trunk where the harvest is harvested, proceed to distribute and install the empty container in a passageway to a suitable place in the harvest area and carry a full container from the passageway and distribute it to a storehouse station.

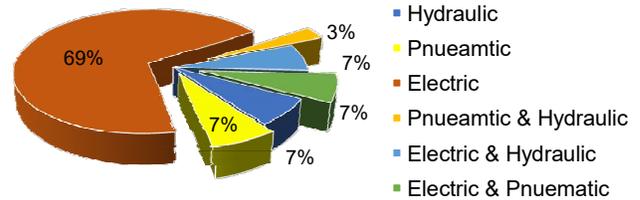


Fig. 9. Breakdown of manipulator actuators used in the robotic harvesting technologies

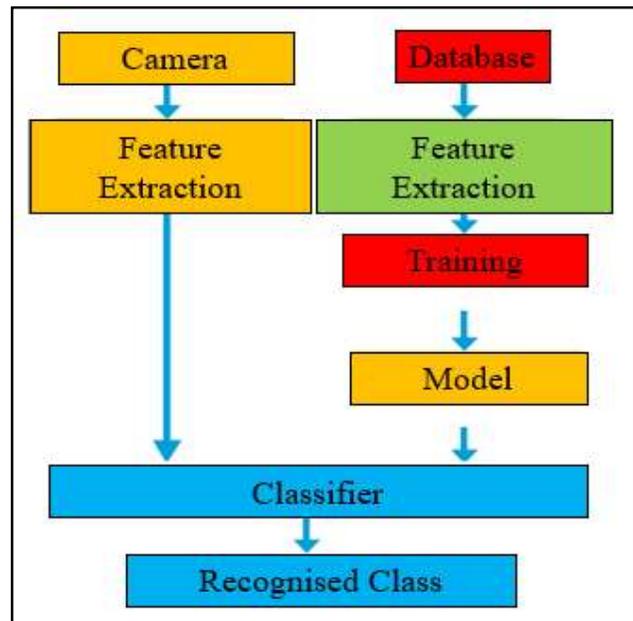


Fig. 10. Fruit classification and quality detection using deep convolutional neural network



Fig. 8. Different types of soft and hollow fingers used in end-effector



Fig. 11. Robotic harvesting applications. “sb”, “tm”, “ap”, “sp”, “cc”, “kw”, “ct”, “rb”, “lc”, “mg”, “pl” represent strawberry, tomato, apple, sweet pepper, cucumber, kiwifruit, citrus, raspberry, litchi, mango, and plum, respectively., **sb-1** Hayashi, 2010, **sb-2** Feng, 2012, **sb-3** Shibuya Seiki, 2014, **sb-4** Yamamoto, 2014, **sb-5** DogTooth 2018, **sb-6** Agrobot-2018, **sb-7** Xiong 2019, **sb-8** Traptic-2019, **sb-9** Harvest CROO-2019, **Sb-10** Octinion-2019, **sb-11** Advanced Farm-2019, **sb-12** Tortuga-2020, **tm-1** Kondo, 2010, **tm-2** Yaguchi, 2016, **tm-3** Zhao, 2016, **tm-4** Wang, 2018, **tm-5** Feng, 2018, **tm-6** Panasonic-, 2018, **tm-7** MetoMotion-2019, **tm-8** Botian-2019, **tm-9** ROOT AI-2019, **ap-1** Baeten, 2008, **ap-2** Zhao, 2011, **ap-3** Nguyen, 2013, **ap-4** Siwal, 2017, **ap-5** Abundant Robotics-2019, **ap-6** FFRobotics-2020, **ap-7** Ripe Robotics-2020, **ap-8** Kang, 2020, **sp-1** Bac, 2017, **sp-2** Lehnert, 2016, **sp-3** SWEEPER-2018, **kw-1** Scarfe, 2012, **kw-2** WilliamsSavoie, 2019, **kw-3** Mu, 2020, **cc-1** Ven Henten 2002, **cc-2** Ji, 2011, **cc-3** IPK, 2018, **ct-1** Muscato, 2005, **ct-2** ENERGID, 2012, **rb** Fieldwork Robotics-2020, **lc** Xiong, 2018, **pl** Brown, 2020, **mg** Walsh, 2019. (Source: Zhou et al 2022)

An efficient navigation system requires a GPS to shift the carrier between the storehouse and the target passageway, and an ultrasonic or lidar-based distance scanning sensor system to identify boundaries and barriers within the passageway where GPS signals are frequently disturbed by the fruit trees (Ye et al 2017). An intelligent management system was used (Zhang et al 2015) to support the efficient harvesting by autonomous containers to independently manage the various operations in the orchard. To plan for effective coordination in a multi-robotics management system, the automated prototype was developed and authenticated an algorithm based on a market-based framework, which had the industrial market value. The developed prototype was capable of making a decision, it will proceed to complete its specific task and make another

decision only after completing its current work. It can be very difficult to carry out all basic work tasks effectively and reliably in a commercial environment, mainly due to enclosed premises with fruit tree passageways, and randomly growing and deformed tree canopy interventions. Kanget al(2020) developed a real-time robotic apple harvesting that included four steps: sensing, verification, grasping, collection, and transportation, as shown in Figure 13.

Future Scope of Artificial Intelligence Robotics Technologies

Market statistics on automation systems in robotics for various agricultural applications are expected to increase from US\$ 7.4 billion in 2020 to US\$ 20.6 billion worldwide by the end of 2025 (Anonymous 2022). Factors such as a reduction in labour, a growing population, and high



Fig. 12. Different types of robotic harvesters with autonomous collection and transportation mechanism

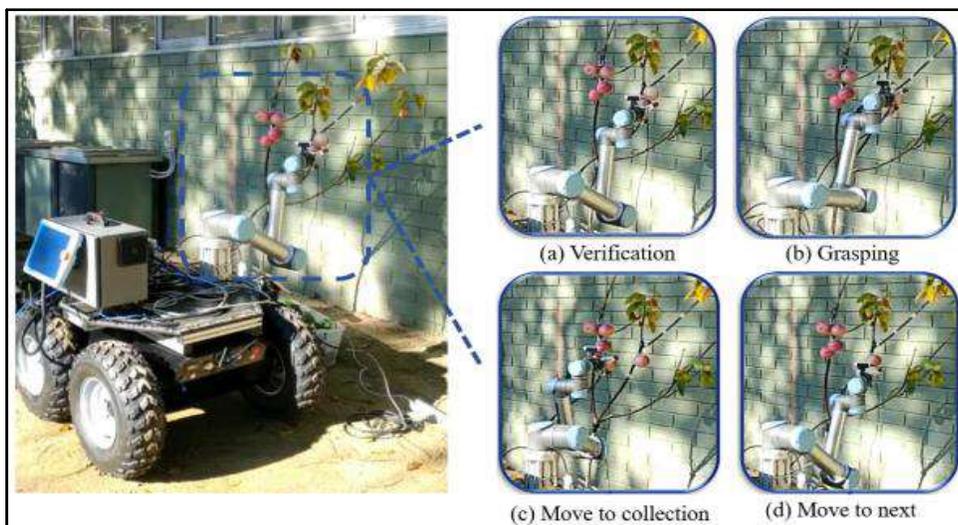


Fig. 13. The process for robotic harvesting experiment in the outdoor environment

productivity needs have enabled the development of agricultural automation and robotics. The difficulty of developing a cost-effective robotic system for fruit harvesting has been discovered by researchers in several parts of the world. The core problems that need to be solved by the robot selection system are to identify, recognise, locate, and detach the fruit without harming the fruit or tree, according to the specified criteria (Anonymous 2020). The development opportunities require tremendous technology maturity to ensure that automated robotics products designed to be implemented in various agricultural activities are reliable and robust. Therefore, a lot of research is still actively being done to overcome many challenges in managing different agricultural activities in different work environments and situations. In addition, the robotic system must be economically sound so that it can be used as an alternative method to manual or conventional methods of fruit harvesting. Despite many challenges in various agricultural activities, the farmers are also more concerned about the total costs required to invest in agricultural robotic systems. Some farmers are afraid to spend their money on technology that won't benefit them in the future. Agricultural researchers must therefore come up with more innovative ideas for designing a multifunctional robotic system at an affordable cost.

CONCLUSION

Robotics and automation play a key role in the horticulture sector for sustaining and boosting food security in the future. The application of robotics equipment lets farmers conduct agricultural operations promptly using a wide range of technologies provided by the advanced system. The artificial intelligence system makes the transition to precise cultivation and harvesting of horticultural crops while helping farmers automate their farms while achieving higher yields and better-quality crops while using fewer resources. Labour is very expensive for gardening. Intensive horticultural products require a more professional workforce than a large-scale agriculture farming approach. Approximately, 50 percent of retail spending is covered by wages on the hired labour leased for various operations. The artificial intelligence-enabled robotic system can reduce farming costs by regulating labour use, efficient use of pesticides and fertilizers, and minimising crop losses by harvesting horticultural crops on time. The application of artificial intelligence robotic harvesting systems in all areas of application will now bring a perfect change in the way it explores and evolves in horticulture. The manufacturing of AI-based products and services such as automated robots, acquiring data through deep learning, flying drone

harvesters, etc., will make technical advances in the future and provide the sector with more useful applications to improve efficiency with the primary objective of producing high amounts of agricultural production in the future in the protection of food security for the world.

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