Review on "Automation in Fruit Harvesting"

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Abstract: - The challenges in developing a fruit harvesting robot are recognizing the fruit in the foliage and detaching the fruit from the tree without damaging both the fruit and the tree. In large-scale greenhouse production, technological developments can reduce production costs; mechanization of crop maintenance and harvesting is one desirable way to accomplish this. Over the last several years there has been a renewed interest in the automation of harvesting of fruits and vegetables. The objectives of this study were to develop a real-time fruit detection system using machine vision and laser ranging sensor and to develop an end effector capable of detaching the fruit similar to the human picker. This paper deals with fruit recognition and it presents the development of a various techniques for the harvesting of fruits.

Keywords: harvesting, detection, recognition, sensor, picker.

I. INTRODUCTION

There is widespread use of robots in industry but much less success in using robots in agriculture. The industrial environment is relatively clean, dry, predictable and well-lit while the agricultural arena is extremely variable in terms of light, weather and terrain. Industrial automation involves uniform components which are robust enough for robotic manipulation, while agricultural automation must deal with crops which vary enormously in terms of colour, size and shape, are frequently partially obscured by foliage and are vulnerable to damage during handling.

There is an economic incentive to use automation in agriculture, particularly in countries with relatively high labor costs (the USA, Italy, Israel, Australia and New Zealand). Manual harvesting of crops is an arduous task and there is a continuing problem with getting and retaining labor to do it. Labor available for this kind of work is reducing day by day making it necessary to automate it.

In this paper, we have included various techniques related to fruit detection and picking. Fruit detection may be done with the help of machine vision (colour and shape), 3D imaging, light sensing and ultrasonic sensing. The results obtained were then used to interpret the locations for picking the fruits and selecting the appropriate fruits as a normal human picker would preferably do. A detail of every technique is discussed following this.

Depending upon the fruit to be harvested (or picked), the automated techniques may vary. Herein, automated harvesting by the following techniques is elaborated:

1) Mechanical Shakers
2) Use of Machine vision by colour
3) Use of Machine vision by shape
4) Use of 3D imaging
5) Use of Ultrasonic sensing

II. MECHANICAL SHAKERS:

Mechanical harvesting methods have been investigated and practiced since early 1960s. Strictly mechanical harvesting systems that are currently being operated, work on the idea of shaking or knocking the fruit out of the tree. The trunk shaker based systems attempt to remove the fruit from the tree by simply shaking or vibrating the trunk of the tree and allowing the induced vibrations and oscillations to cause the fruit to fall out of the tree. Canopy shaker systems, see figure 2, and typically use larger rotating drums with protruding “fingers” that are inserted into the tree's canopy. The rotating fingers allow for better shaking of the canopy than the trunk shakers alone.

However, it may require a large amount of shaking before the fruit can be harvested which can cause several problems. The first is that the shaker system may cause physical damage to the tree such as bark removal and broken branches. Second, and most importantly, the fruit has a high probability of being damaged by either the shaker system or falling out of the tree, and thus mechanical shakers systems are typically only used for juice quality fruit.

The focus of most research efforts has been to design a harvesting system that can replicate the precision of a human harvester while achieving the efficiency and decreased labor of the purely mechanical harvesters. To reduce the physical damage to the tree, a pre-harvest abscission spray was also proposed to loosen the fruits on the tree. In order to improve the design of mechanical harvester the biological and physical properties of the fruit were also studied

This section will review those mechanical harvesting methods. The mechanical harvesting methods reviewed here are limb shaking, air blasting, canopy shaking, trunk shaking, and the use of an abscission chemical agent to loosen the fruits.

A. Limb Shaker

An early limb shaker was represented by Coppock and Jutras using inertia developed by Adrain and Fridley. An eccentric weight about 85 pounds was rotated in the mechanism to produce the shaking action after the shaker was attached to the tree limb. Notably some damage was made to the bark of the tree by the clamping mechanism. An alternative tree shaker was represented using fixed stroke, inertia, and direct impact on tree limbs. The issues from this practice included such as fruit damage due to fall foliage, lower removal rate in earlier and mid of harvesting season, and large or small immature fruit removal. Another tree shaker with two catching frames each with an inertia type limb shaker was developed. Still, immature fruits were removed with damages to the fruits. A self-propelled limb shaker was tested on Valencia orange. A self-propelling full powered positioning limb shaker was also evaluated with abscission aid by Summer and Hedden. [1].

Figure 1: Limb Shaker

B. Air Blast

The application of force generated by air blast to remove the fruit started in 1961. An oscillating air blast machine was tested and practiced by Jutras and Patterson. Fruit removal was maximized by the oscillation rate. The air blast model and all the subsequent models were made and named after FMC (Food Machinery Corporation). The performance of FMC series was dependent on factors such as structure of tree, size and weight of fruits. Later, an air shaker was designed and constructed to alleviate issues such as the high power requirement. However still damages to the fruits and leaves were the major issues addressed in the project. [1]

Figure 2: Air Blasting Machine

C. Canopy Shaker

A canopy shaker was designed to clamp secondary limbs and to shake vertically. The shaker was extended into tree with a pantograph lift unit and shake always vertically. An excessive immature orange were removed during tests conducted by Summer. Two continuing canopy shakers were reported by Futch and Roka, one was self-propelled unit and another was tractor-drawn unit. These two units were used for juice processing plants. Manual workers were needed to collect the fruits after the harvest.

Shaking frequency and stroke are important factors in the performance in this type of harvester and it requires more tests to determine the optimal values. [1]

Figure 3: Canopy Shaker

D. Trunk Shaker

Trunk shaker was used to remove deciduous fruits and nuts but difficult to apply this technique on citrus fruit removal. However, Hedden and Whitney designed the experiment to evaluate the trunk shaker for earlier season Hamlin orange and late season Valencia orange using different unbalanced mass and multidirectional shakers for years. The linear low frequency shaker with a larger displacement performed better than the canopy shaker machine. The bark was more or less damaged during the experiment. Later the trunk shakers were tested along with other canopy shakers by Whitney. The efficiency of removal was from 67% on large trees to 98% on small trees. More recently, a tractor mounted trunk shaker was tested on varieties of oranges and mandarins in Spain by Torregrosa in comparison to a hand-held shaker. Overall the tractor mounted shaker was more effective with 72% detachment than the hand-held shaker with 57% detachment. In test, the fruits picked up from ground had high percentage of bruise. Defoliation was high at high shaking frequency and the bark was damaged in season of May and June. [1]

Figure 4: Trunk Shaker

E. Abscission Chemical

Abscission chemical agent was designed to loosen the mature fruit and improve the rate of removal of fruit in harvesting season. There are many kinds of abscission agent such as Ethephon and 2-chloroethyl phosphoric acid. The use of abscission agent was applied as pre-harvest process and constituted part of harvesting such as air shaker. Air shaker was tested with applying abscission agent in advance on FMC-3 by Wilson et al. Limb shaker used abscission to loosen the fruit on stem. It was noted that abscission chemical was inconsistent in practical use. The abscission use was subjective to many factors such as weather factors, tree injury, and cost of using chemicals. The Prosulfuron, an abscission chemical agent which was used on Hamlin and Valencia oranges loosening, were studied by Kender et al. This abscission was more effective in Hamlin than others. However, the immature Valencia was loosened before harvest. The CMN-P abscission chemical was tested on 'Hamlin' orange before the harvesting by trunk shaker. [1]

III. MACHINE VISION TECHNIQUE BY COLOUR

This Technique can be illustrated by an example of a strawberry harvesting robot.
The fruits of strawberry hang in midair, so they are easy to detect and pick. Here a strawberry-harvesting robot was developed to take advantage of this. The prototype includes a stereoscopic visual sensor, artificial lights, an actuator with three degrees of freedom, an end effector to pick strawberries, a traveling carriage, and a controller. (Fig. 5)

Figure 5: The strawberry-harvesting robot

The harvesting procedure is as follows.

First, the robot searches for red fruit by taking RGB (red, green, blue) images. A red area in an image satisfies the following equation:

$$0.58 < R1 < 1,$$

Where R1 = chromaticity of the R component

$$= R / (R + G + B).$$

The robot was designed to run at night, so the background of a captured image is almost black, and robot should easily detect ripened fruits (Fig. 6).

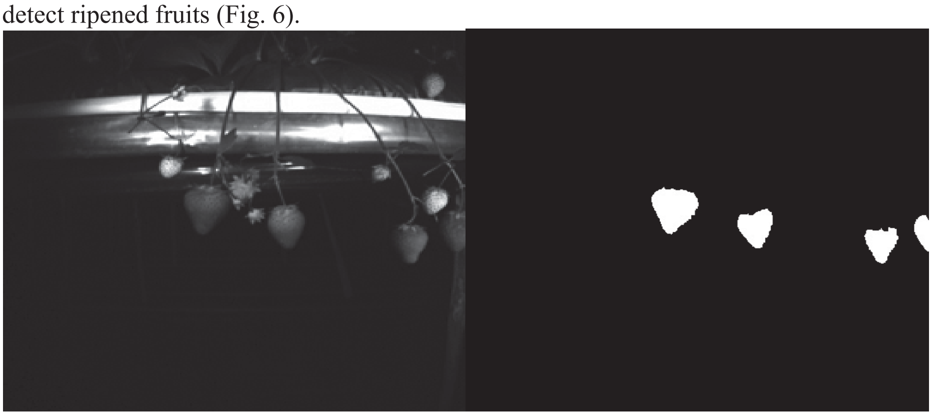

Figure 6: The detection of ripen strawberries by machine vision

Second, RGB images are transformed into HSI (hue, saturation, intensity) images, and green areas (unripe parts of fruit) are detected by selecting the area just above the red area and determining whether the green area satisfies the following conditions:

$23 < hue < 48;$

$62 < saturation < 255;$

$141 < intensity < 220.$

Third, maturity level is calculated as the ratio of the red area to the green area:

$$M = A_r / (A_r + A_u) \times 100,$$

Where: M = maturity level (%);

A_r = area of red ripened part (pixels);

A_u = area of unripe part (pixels).

If the maturity level is over a certain value, the position of the fruit is calculated stereoscopically.

Fourth, the end-effector approaches the target fruit, guided by the controller. A vacuum nozzle attached at the tip of the end-effector and covered with soft material holds the fruit. A cutter holds and cuts the peduncle. Finally, the robot transfers the fruit into a tray nearby, and the actuator returns to its original position.

The robot cannot detect and approach fruit that is occluded by other unripe fruit. So we investigated the exposure level of strawberries in the greenhouse. Digital pictures of ripened fruit were taken from the passage side and classified into 4 levels of exposure for fruit and 2 levels for peduncles according to the definitions in Table 1.

Table 1 Classification of exposure level of strawberry

Part	Level	Explanation
Fruit	A	Whole fruit is visible and separated from others.
	B	Whole fruit is visible, but other adjacent fruit might be behind.
	C	Fruit exposure is 50% or more.
	D	Fruit exposure is less than 50%.
Peduncle	G	Whole peduncle is visible.
	N	Part of peduncle is not visible.

Then we compared machine vision and human judgment at gauging maturity. Seventy fruits with a maturity level of more than 40% and an exposure level of A were used, because the machine vision considers small red areas as noise.

Finally, we conducted harvesting experiments using 20 fruits of exposure level A to assess the need for further development. While the robot was stationary, the number of successful picks was counted and harvesting time per fruit was measured. [4]

IV. MACHINE VISION TECHNIQUE BY SHAPE

Machine vision technique by shape can be most suitably used for citrus fruits. Many different researchers such as Whittaker (1987), Pla(1993), Grasso(1996), Levi(1998) and Phebe(2001) have incorporated shape into their fruit detection algorithms. Citrus in general tends to have a round shape, whereas tree branches and leaves tend to have more straight and pointed shapes. Looking for round objects can be simple way to detect fruit, but as with colour detection, shape detection can also have several problems. The main problem is occlusion. Fig 7 shows images of the two main types of occlusion when observing oranges. Figure 7(a) is an example of leaf occlusion. Leaf occlusion complicates fruit detection by disrupting the shape of the fruit and minimizing the amount of the fruits color that is visible. Figure 7(b) is an example of fruit occlusion caused by clustering of several fruits. Fruit occlusion also disrupts the shape of the fruit in much the same way as leaf occlusion. Fruit occlusion can cause multiple fruit to appear as a single large fruit, unlike leaf occlusion where there is distinct contrast in colour between the leaf and the fruit.

(a) (b)

Figure 7: Occlusion Problems: (a) Leaf and (b) Fruit Clustering

Another situation that is important is that there are certain varieties of orange trees that grow both the current season's harvestable fruit as well as next year's immature fruit. The result is that the tree will have both orange and green colored oranges at the same time.

A successful citrus detection strategy will require the understanding and full exploitation of both the colour and shape of the fruit. Image processing will be needed to determine how to best detect the color in a variety of lighting conditions, while at the same time being able to compensate for the differences in the fruits natural colour. Image processing will also need to detect fruit when leaves or branches occlude it, or when it is clustered with other fruit. A fruit detection algorithm that is economically feasible for mass harvesting will require a combination of both the colour and shape properties of citrus. [2]

Figure 8: Robot with machine vision for shape

VI. 3D IMAGING

This Technique can be illustrated by an example of a cucumbers harvesting robot.

In Fig. 9 a functional model of the harvesting robot is shown. It consists of an autonomous vehicle, a 7 DOF manipulator, an end-effector, 2 camera vision systems and miscellaneous electronic and pneumatic hardware. Each module will be described hereafter in some detail. [5]

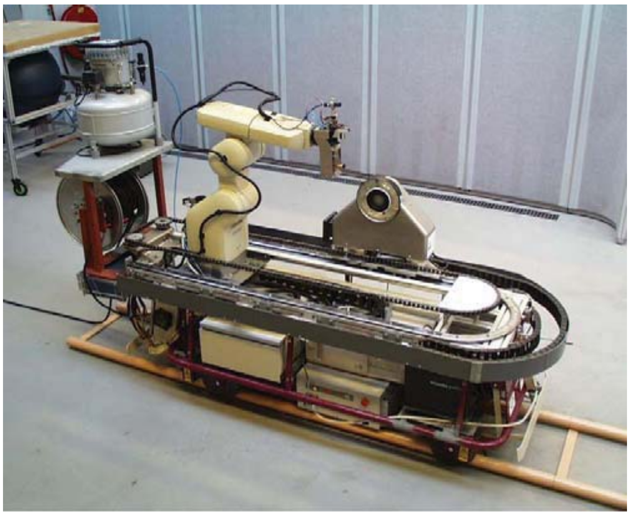

Figure 9: A functional model of the harvesting robot.

A. The Autonomous Vehicle:

The autonomous vehicle moves the harvesting machine along the aisles of the greenhouse. The vehicle uses the heating pipes mounted on the ground as a rail for guidance and support. It serves as a mobile platform for carrying power supplies, a pneumatic pump, electronic hardware for data-acquisition and control, the camera vision systems and the seven DOF manipulator with the end-effector for cutting the fruit. During a harvest operation the mobile platform gains stability by putting 4 linearly actuated struts on the ground. Currently, due to the considerable energy consumption of various components used, the robot is not completely self-supporting in terms of electric power supply. Operation of this machine depends on a life-line mounted on a reel, which carries 220V from a central main supply to the robot. The vehicle is driven by a 24V DC motor and its acceleration is limited to approximately 0.3 m/s^2. [5]

B. The Manipulator:

The robot contains a 7 DOF manipulator for positioning of the end-effector during the harvest operation. The manipulator consists of a linear slide on top of which a Mitsubishi RV-E2 manipulator with an anthropomorphic arm and a spherical wrist is mounted. The particular choice of the manipulator geometry was based on a combined analysis of the robot task and the working environment. In the high-wire cultivation system, the ripe cucumbers all hang in a limited band between 0.8 m and 1.5 m above the ground. Then, using the vehicle for transportation along the aisles of the greenhouse, an empirical analysis revealed that 6 DOF consisting of 6 rotational joints would be sufficient to perform the harvest operation. Limitations had to be put on the geometrical and physical properties of the manipulator because it has to deal with dense and rather fragile canopies. Also the amount of space between the rows of the crop is limited. [5].

C. The End-Effector

The end- effector contains the following parts: a gripper and suction cup to grasp the fruit and a thermal cutting device to separate the fruit from the plant. Figure 10 shows a close-up of the end-effector, including the gripper and the cutting device. The light weight camera mounted on top of the end-effector is not shown in this figure.

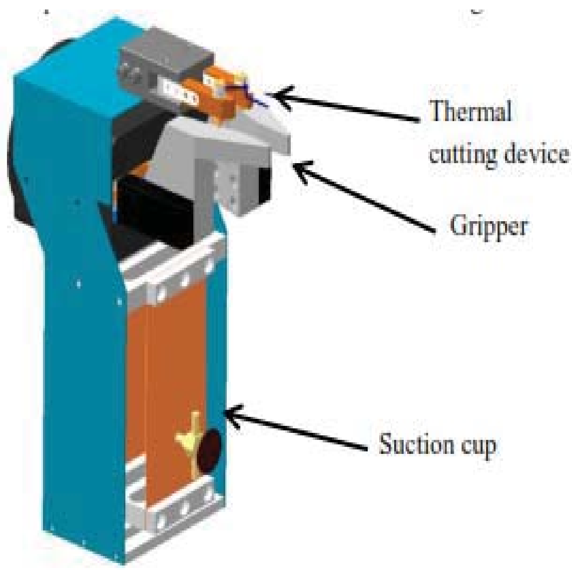

Figure 10: A close-up of the end-effector.

Essentially, the gripper used in the cucumber harvester is a modified version of the Mitsubishi motor gripper 1E-HM01. Design requirements for the modified gripper were that it should have sufficient grip on the fruit during cutting and transportation of the fruit to the storage crate. However, since we are dealing with a delicate product, mechanical stress that reduces the quality of the fruit had to be prevented. The required and permitted forces were determined empirically. During the harvest process the two fingers of the motor gripper, grip the stalk of the fruit. Once the fruit has been cut, the suction cup mounted below the gripper fingers immobilizes the fruit during the transportation phase. Upon arrival at the storage crate, the fruit is put in a horizontal orientation and gently lowered into the storage crate. Then the gripper releases the fruit.

The design of the cutting device required additional attention. In horticultural practice, the grower uses a knife to cut the stalk of the cucumber fruit. By using the same knife over and over again, there is a risk of transportation of viruses from one plant to the other. In horticultural practice this is prevented by immersing the knife in skimmed milk before each plant contact. For a robotics application this approach was not considered to be practical. For automated cutting of the cucumbers stalks a thermal cutting technique from medicine was adopted. It employs two electrodes carrying a high-frequency electrical potential. [5]

D. The Vision Systems

The harvest robot carries two camera systems. One camera is mounted on the vehicle on a rail that extends on both sides of the manipulator with a bend at the head- end of the vehicle. This construction offers the opportunity to use the camera for inspection of the crop on both the left-hand and the right hand side of the vehicle. Also, this camera is able to move independent from the manipulator. The other camera is a lightweight system mounted on top of the end-effector. Each camera system has a different task. The camera mounted on the vehicle is used for the detection of the fruit, determination of the ripeness and quality of the fruit and 3D localization of the fruit for robot motion planning. The camera mounted on top of the end-effector is used for stereo imaging in the neighborhood of the cucumber during the final approach of the cucumber with the gripper. [5]

a) Detection of fruit

Fruit detection is an intricate problem because the green cucumber fruit have to be found in a green plant environment. From the two main approaches, (a) recognition based on shape and (b) recognition based on spectral properties, the last seems to be the most promising. The camera system on the vehicle uses two synchronized charge coupled device (CCD)-cameras mounted onto one wide angle optical system.

An experiment in a greenhouse was carried out in autumn 2000 to determine the accuracy of the vision system. For this experiment 126 stereo-images of a plant stand of cucumbers were acquired. The crop was grown in the high-wire cultivation system. At the time of the experiment there were 106 ripe cucumbers in the analyzed harvesting zone. Images were taken every 0.33 m using the camera mounted on the vehicle while moving the vehicle along the plant row. The relatively small motion of 0.33 m between two successive images ensured, that every part of the plant stand was three times in the camera's field of view but from different perspectives. By doing so, the effect of leaves or other plant-parts hiding the cucumbers from certain points of view was minimized. If a cucumber was detected in at least one of the three images it was counted as detected.

More than 95% of the cucumbers were correctly detected in this way. During the experiment 11 times leaves or parts of leaves were detected as fruit and 8 times stems were detected as fruit. The reasons for not detecting the fruit were mainly caused by illumination problems (reflection, flash intensity too high or too low), problems with separating two cucumbers, problems with separating fruit and stem, and by cucumbers completely hidden behind leaves. For the current stage of the project these results were considered to be sufficient. Actually these results can stand a comparison with the performance of a skilled worker during manual harvest in a conventional cultivation system.

b) Determination of ripeness and quality

Cucumbers, as many other fruit, do not ripen at the same time and, consequently, every cucumber has to be evaluated for ripeness (classified) prior to harvesting. In practice, the main criterion for ripeness is the fresh weight of the cucumber, which should lie in the range of 300 g to 600 g. So, to determine the maturity of cucumbers, an accurate non-destructive method for estimating the fresh weight was developed. The fresh weight of the cucumber is linearly related to the volume of the fruit. Research revealed that using a geometric model of the cucumber volume, the weight of cucumbers could be estimated with a correlation of 97%. A volume reconstruction using the distance transform yielded less accurate results. Figure 11 illustrates the approach.

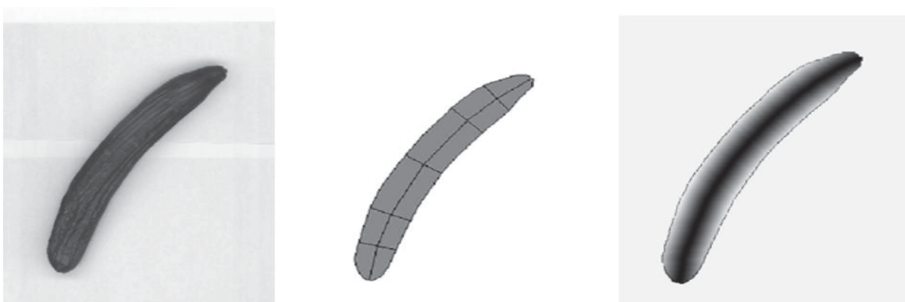

Figure 11: Geometrical parameter determination and volume reconstruction using computer vision (left image: original image of cucumber, center image: geometric model based on measurement of length, width and area, right image: volume reconstruction based on the Distance Transform of the silhouette).

c) 3D localization of fruit

Both the camera on the vehicle and the camera on the end-effector are able to move on a rail. By taking two images from a slightly different perspective it is possible to perform a 3D-scene reconstruction using standard triangulation techniques. The accuracy of the 3D reconstruction depends on the accuracy and repeatability of the camera shift and calibration of the camera model. The former was achieved by using low tolerance slides for shifting the cameras. For the calibration of the camera a procedure was used based on the work of Zhang (1999) and Heikkilä and Silven (1997). For objects at a distance of 0.6 m from the camera, the camera mounted on the vehicle produces a maximum error of 1.5×10^{-3} m in the x-plane and y-plane and about 7.5×10^{-3} m in the z-plane, perpendicular to the CCD-chip. Figure 11 shows a result of the 3D imaging with the camera mounted on top of the end-effector. It shows a close-up of the top of the cucumber fruit, the fruit stem, as well as the stem of the plant and a leaf stem. This image contains 3D information. The light-grey parts lie close to the camera, whereas the black objects lie further away from the camera. [5]

VII. ULTRASONIC SENSING

This Technique can be illustrated by an example of an eggplant harvesting robot. We designed a robot to harvest eggplants (Solanum melongena) trained on a V-shaped frame. The robot includes sensors (CCD camera and ultrasonic distance sensor), a manipulator with seven degrees of freedom, an end-effector, a traveling carriage, and a controller (Fig. 12). The sensors are attached to the end-effector (Fig. 13). The robot runs between rows and scans images of the eggplants on both sides through a combination of travel and manipulator control in the order.

Figure 12: The eggplant-harvesting robot

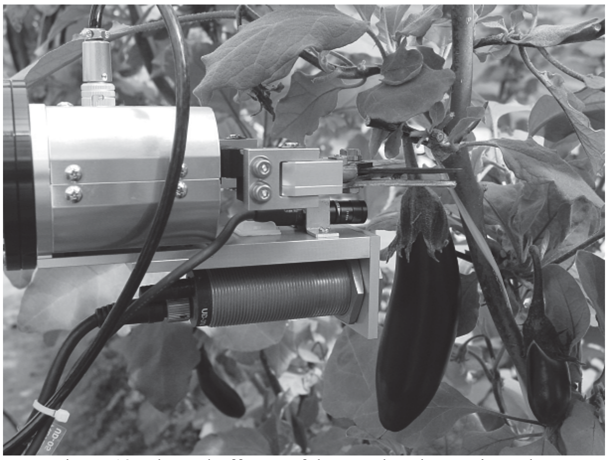

Figure 13: The end-effector of the eggplant-harvesting robot

The visual sensor has two functions: global and local sensing. When the global sensor detects an eggplant, the end-effector approaches the fruit and stops at 160 to 250 mm in front of it. At this point the fruit length is estimated by the visual sensor and the ultrasonic distance sensor. If the fruit is of marketable size (>120 mm long), scissors hold and cut the peduncle. Finally the robot transfers the fruit to a container.

Experiments were conducted in a greenhouse. Plants of cultivar 'Senryo-2' were planted 400 mm apart in a 4-m row (Fig. 7). The numbers of total and marketable-sized fruits were counted beforehand, and then after harvest we calculated the successful harvesting rate, undersized-fruit harvesting rate, harvesting time per fruit, and total harvesting time. This study shows that the robotic system can harvest marketable-sized eggplants without damage, although further development is necessary. [4]

VIII. CASE STUDY

Development of an Autonomous Kiwifruit Picking Robot

A. Literature Review:

Research into the automated harvesting of discrete crops (as opposed to bulk grains and grasses) initially began in greenhouses where the structured environment, high plant density and high product value justified the expense of robotic picking. Van Henten et al describe an autonomous robot for harvesting cucumbers but only 80% of the cucumbers are picked and the average pick-rate is 45 seconds per cucumber. Belforte et al review robotic harvesting of mushrooms, lettuce and strawberries in greenhouses and note that these are not commercially viable because they are too specific in their purpose (picking is typically a very short period in the life of the crop) and have an unattractively slow pick-rate. They developed a proof-of-concept stationary robot capable of under-leaf spraying and precision fertilization of potted plants which were moved on a conveyor past the stationary robot with a cycle time of 7 to 8 pots per minute. Although the dual functions of the robot mean that it can be used for a greater portion of the plant life, the cycle time is too slow for commercialization and the problems associated with moving the plants rather than the robot are large.

The history of research into the area of automated outdoor fruit picking is given by Muscato, Prestifilippo, Abbate, and Rizzuto who note that the two main problems with robotic fruit picking are having a vision system capable of recognizing the fruit and having a grasping device which doesn't damage the fruit. They review the research in both of these areas. Amore detailed review of robotic manipulators (called 'end-effectors') in horticulture is provided by Tillett. Another problem with autonomous robotic picking is the navigation of the robot through the orchard. Guidance systems use either Global Positioning System (GPS) technology or computer vision. [3]


Figure 14: Kiwi Fruit [6]

B. Design Concept For The Autonomous Kiwifruit Picker

The kiwifruit picker being developed in New Zealand is an autonomous four-wheel drive vehicle with the following design attributes.

It is powered by a 7 kW petrol generator, coupled with a hydraulic pump. The robots are electrically driven, while steering and motion are hydraulic. The vehicle is about 2.3 m long by 2 m wide and, with a full bin of kiwifruit, weighs 1.5tonnes. The system runs on two commercial dual-process or mother boards which handle all aspects, including vision.

A robot was custom designed and built for this application. Four of them are deployed on the picker. This step was necessary because the use of anthropomorphic commercial robots would be prohibitively expensive and also excessively heavy. Secondly, the interface with a commercial robot is not flexible and we require it to be able to produce customized movement trajectories. The robots use an advanced technology so that they can be driven by stepper motors without the need for encoder feedback or trapezoidal profile stepper controllers. The technology (discussed below) leads to a performance increment of about 100% over the standard stepper control technology.

The vehicle uses a combination of GPS and intelligent computer vision to navigate the kiwifruit orchards; maneuvering around obstacles such as posts and 'dead-men' and recognizing braces. The vision system identifies fruit hanging from the canopy, discriminating for size and gross defects. Each of the four robotic arms picks the 'good' fruit and a robotic system places it gently into the bin at a rate of four fruit per second. The vision system checks the fruit level at each point in the bin and adjusts fruit placement to fill the bin evenly. When the system determines that the bin is full, the vehicle goes to the end of the row and puts the bin down. The vision system then searches for an empty bin and adjusts its approach trajectory so that it can engage its forks into the bin.It picks up the bin and then returns to its last position and resumes picking.

The vehicle operates continuously, sensing when it needs to re-fuel and navigating to the fuel supply point. The vision system checks for light level and operates floodlights if necessary. It also checks for rain or dew and covers the bin with a tarpaulin when this is detected so that picked fruit is protected. The system can go into secure mode (for example when the fruit is wet and should not be picked), moving the robotic arms to a safe position, switching the unnecessary power systems off, and maintaining battery power only to the main (monitoring) computer and radio link. The system 'wakes up' when appropriate and resumes picking. It receives and responds to communications via radio link. It uses a variety of recovery strategies to deal with faults such as getting stuck, vision becoming obscured, etc. Data is collected on the fruit yield from a particular orchard and this is sent to appropriate places such as the pack house which will be packing the fruit.

In existing New Zealand kiwifruit pack houses, approximately 30% of the fruit is rejected on the basis of size and quality. The fruit growers pay the pack house a packing fee which is based on the gross tonnage with a fine for rejects. The ability of the vision software to recognize fruit which is undersize, mishapen or marked is consequently enormously economically attractive to the growers. [3]

C. Current Status of The Autonomous Picker

The vehicle and picking arms have been built and are shown in Figures 15, 16 and 17. The major systems are at the following stages of completion *a) The Vehicle*

The chassis is complete and the control system for the hydraulic drive is functional. The main computer provides a slave computer with information on the center of rotation for the vehicle's turn and tangential speed around this arc. The center of rotation lies on a line connecting the two back wheels and the vehicle is capable of turning about either of the back wheels. The maximum speed of the prototype is 6 km/hr.

b) The Robot Arms

The four robotic picking arms were custom-designed and built. They are complete and have been programmed to do asynchronously two types of move. The first of these is a 'go to' move where the arm proceeds from its current position in 3-space to a specified position. The second is a complex picking move. This move starts from a position where the hand is enveloping a fruit. The hand closes on the fruit and rotates it in such a way that the stem is bent while the hand lowers itself, thus breaking the stem appropriately. Simultaneously, the robot arm moves the hand down, across and up to the next fruit. At the mid portion of the movement, the hand opens and releases the fruit into a recovery chute. This move takes under one second; the control (main) computer sends the slave computer the position of the next fruit and the slave computer executes the next picking cycle. Communication between the two computers means that the main computer knows when the slave has completed the cycle for each of the four arms - which operate asynchronously.

All four picking robots are controlled by one core, on a CPU running at 2.5 GHz. The control runs under DOS, using QuickBasic. This legacy language and legacy OS were chosen as the easiest and cheapest way to get 'edit and continue' programming without latency issues. The timesharing code necessary to provide step and direction, asynchronously, in real time, at 10 kHz for twelve stepper motors was written in QuickBasic. The code turned out to be economical and friendly.

Figure 15: The autonomous kiwifruit picker

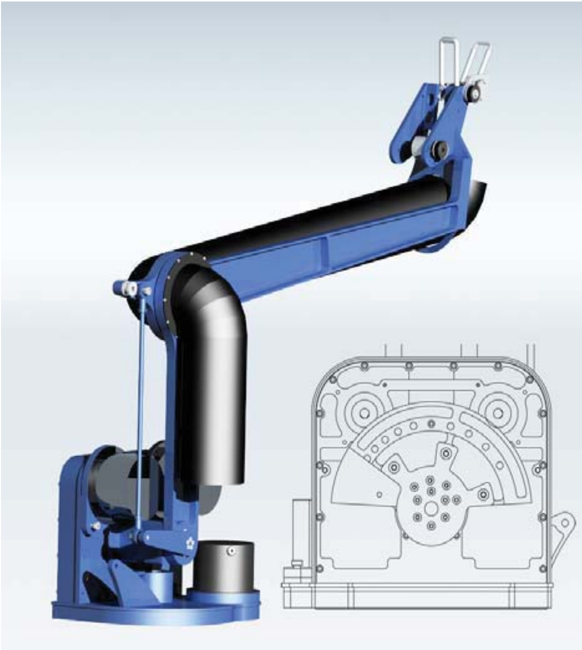

Figure 16: Robotic arm with detail of lower and upper arm drive.

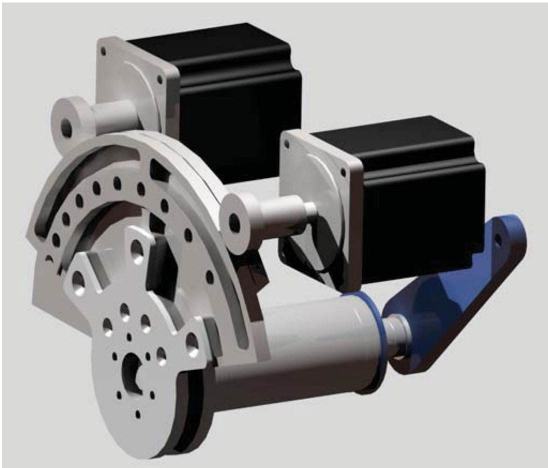

Figure 17: Lower and upper robotic arm drive chain.

c) Navigation

The system has functional differential GPS and a compass which are together used for navigation when the vehicle is not under the kiwifruit canopy. When under the canopy, the picker relies upon two forward facing cameras in order to find its way. This system is functional and permits the picker to drive down the aisles of the orchard, turn when it reaches the end and come back up the aisle, picking the area between the poles in two swathes. The vision system uses navigational cues provided by the lines of poles which define the lanes. Hough Transforms are very efficacious in defining the pole edges. These provide information from which the edges of the lane, its direction and its extent can be derived.

Commercial colour cameras (640 x 480 pixels) with auto-iris lenses and frame grabbers are used for navigation and bin manipulation. Eight Webcams are used to look up into the canopy, to identify fruit and to perform stereopsis in order to determine the three positions coordinates of each fruit. Because the Webcam lenses are very short (3mm), provision has to be made to handle fisheye in the stereopsis.

The vision software has enough intelligence to perceive obstacles and the system can take appropriate action. The vision algorithms described by Flemmer and Bakker are used for obstacle recognition and the handling of bins. [3]

D. Conclusion

With the exception of the automated kiwifruit picker described in this paper, there is no report of a commercially viable picking robot. The contenders lack adequate vision, adequate navigation, adequate delicacy of fruit picking and handling and adequate speed/commercial payback. The present robot has demonstrated capability in all these areas, particularly the ability to use artificial vision for navigation and bin management, without artificial visual markers.

IX.CONCLUSION

The fruit harvesting systems have been reviewed in this paper. The main applications from both mechanical harvesting systems and automatic harvesting systems have been collected. In addition, the machine vision system has been focused covering the sensor schemes and methods behind them. From the literature, mechanical harvesting systems show the advantage in mass production. The automatic harvesting systems have been practiced to tradeoff the selection capability between the conventional labor harvester and mechanical harvester.

The detection algorithm and the harvesting end-effector are designed to suit the target fruits. The design of harvesting robots for practical use needs information on crop features (color, shape, and size) and the development of appropriate crop maintenance and environmental conditions. The accuracy is enough to use in automatic harvest systems.

REFERENCES

[1] Peilin Li, Sang-heon Lee, Hung-Yao Hsu, “Review on fruit harvesting method for potential use of automatic fruit harvesting systems”.
[2] Michael Hannan, Thomas Burks, “Current Development In Automated Harvesting”.
[3] A. J. Scarfe, R. C. Flemmer, H. H. Bakker and C. L. Flemmer, “Development of An Autonomous Kiwifruit Picking Robot”.
[4] Shigehiko HAYASHI, Tomohiko OTA, Kotaro KUBOTA, Katsunobu GANNO and Naoshi KONDO, “Robotic Harvesting Technology for Fruit Vegetables in Protected Horticultural Production”.
[5] E.J. Van Henten, J.Hemming, B.A.J. Van Tuijl, J.G. Kornet, J. Meuleman, J. Bontsema And E.A. Van Os, “An Autonomous Robot for Harvesting Cucumbers in Greenhouses”.
[6] Shuai Su, Longsheng Fu, Fanian Zhang, Yongjie Cui, “Image Acquisition Method of Kiwifruit Picking Robot”.