Automated Crop Harvesting, Growth Monitoring and Disease Detection System for Vertical Farming Greenhouse

Charith Jayasekara, Sajani Banneka, Gihan Pasindu,
Yukthi Udawaththa, Sasini Wellalage and
Pradeep Abeygunawardhane

October 9, 2021

Automated Crop Harvesting, Growth Monitoring and Disease Detection System for Vertical Farming Greenhouse

Charith Jayasekara
Dep. of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Malabe 10115 , Sri Lanka
shanakajayasekara5111@gmail.com

Sajani Banneka
Dep. of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Malabe 10115 , Sri Lanka
sajanibanneka2@gmail.com

Gihan Pasindu
Dep. of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Malabe 10115 , Sri Lanka
gihanpasindu@gmail.com

Yukthi Udawaththa
Dep. of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Malabe 10115 , Sri Lanka
yukthiprabhath96@gmail.com

Sasini Wellalage
Dep. of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Malabe 10115 , Sri Lanka
sasini.w@sliit.lk

Pradeep Abeygunawardhane
Dep. of Computer Systems Engineering
Sri Lanka Institute of Information Technology
Malabe 10115 , Sri Lanka
pradeep.a@sliit.lk

Abstract - Greenhouses are a type of cultivation method used to optimize the production of crops by using controlled climatic conditions and other external factors. They are widely used in agriculture both globally and locally. Vertical farming is the modern practice of growing crops in vertically stacked layers in warehouses that aims to optimize and develop plant growth by using controlled environment agriculture. This type of agriculture concept is practiced in Sri Lanka at present. This research paper proposes a robot which consists of a specific navigation system and harvesting mechanism that can be used inside greenhouses. The proposed system can be implemented to harvest lettuce in the vertical farming greenhouses where lettuce needs to be harvested with care to ensure the supermarket quality. The above-mentioned system helps to detect the diseases of plants also where a lot of time can be saved, and less effort is made with the use of this type of implementation.

Keywords - vertical farming, robotics, automation, harvesting, navigation, greenhouse.

I. INTRODUCTION

It is estimated that the world population would reach 9.8 Billion by 2050 and to feed such a great population, food production should be accelerated. Fresh fruits and vegetables should be cultivated to feed the increasing population day by day[1]. According to the report published by Food and Agriculture Organization (FAO) in 2015, it states that the number of Agri businesses must be increased by 2050 to meet the increasing food demand in cities and urban areas. In addition, it is very important to mention that more sustainable ways of producing food are needed to prevent the massive food waste globally.

Greenhouses are a special type of cultivation used to grow crops under specially controlled environmental and climatic conditions such as light, temperature ,humidity etc. The vertical farming greenhouse is a special type of cultivation where crops are grown in vertically stacked-layer-like racks to get the maximum use of the land [1] which is a scarce resource in cities and vertical space which is not used efficiently in traditional farming. Although the initial investment is high, empty warehouses are set up with the infrastructure like racks, lighting, and farming is started.

Many different tasks such as planting, monitoring, and harvesting of crops are done in a vertical greenhouse that requires a lot of human labor which is a limited resource and much expensive. Due to the methods and procedures used in the vertical greenhouse [2], it is very difficult and monotonous for humans to interact with the actions happening there. As a solution , agricultural robots have more attraction nowadays. Many types of research have been done on this area where robotic automation is used in agriculture which eliminates the use of human labor.

One of the soil-less farming method used in agriculture sector is Hydroponics, which is a technique used to grow crops by submerging them in a nutrient solution consisting of different types of minerals[1]. At present the hydroponic technology implemented in vertical farming greenhouses enhance the sustainability of the systems and increase the yields while reducing the costs of maintenance. Different types of robotic systems have been used for the harvesting , navigation mechanisms within Lettuce vertical farming greenhouses.

This research is mainly focused on designing an automated robot intelligent enough to navigate towards each plant inside the greenhouse , detect lettuce in real time to identify and harvest good quality crops, plant growth monitoring, plant disease detection on lettuce based hydroponic vertical farming greenhouse. This type of solution minimizes the use of human labor and reduces the time consumed during harvesting process with increased quality and productivity. Food wastage is also minimized with the practice of this type of solution.

II. LITERATURE SURVEY

Group of researchers developed robot called 'TackBot' which included cable driven continuum Manipulator with two actuators. The continuum equipped with two parts with five separate segments for each and it consist of two separate disks which connected by universal joint and four compression springs for enhance rigidness of the manipulator [3]. The flexible structure of the manipulator provides the ability to work in confined workspace with minimizing the damage that can happen from the manipulator to the plant and their harvest.

A stereo vision camera system is used by using two inexpensive web cameras to get the relative position and the distance to the object. It is a cost-effective solution instead of using a single stereo vision camera. Here the position is read analytically by estimating the target relative position and distance from both point of views taken by the two cameras on the same object. The navigation robot [4] in here is based on the 3D printer frames and used the Computer Numerical Control or CNC technology used in there.

A Research named Construction and evaluation of low-cost table CNC milling machine' by Ivo Pahole & Luka Rataj [5] discussed about a CNC machine. It was operated as an efficient high weight 3-axis simultaneous intercorporate machine. This was a low-cost milling machine which is integrated with CNC machine technology. It was an Arduino based embedded system which enables with a PC interface with a microcontroller.

This CNC technology is mostly used in sketching a picture. Rather than sketching CNC machines are mostly used in various large-scale factories, workshops, and industries. Those CNC machines are very complicated, and their design is based on heavy metal parts. A lows costs CNC plotter machines has come to the stage to mitigate the difficulties on earlier CNC machines such as large size, high cost, difficulty of moving [6]. These portable plotter CNC machines have become popular in case of perform sketching. Research in [7] developed a CNC Based agricultural robot with a novel tomato harvesting continuum manipulator tool. There a robot named 'FaRo (Farming Robot)' has been developed with the intention of harvesting crops autonomously without any interference of human. CNC platform design was developed for the robot design integrate with x, y, z axis and a universal mount system. It facilitates the process of farming form the seeding to the harvesting

Authors of paper[8] has implemented a cucumber harvesting robot to harvest cucumbers. Although cucumber fruits are hard to be detected by computer vision algorithms because of their special green color and irregular shape, a pixel-wise instance segmentation method called mask region-based convolutional neural network (Mask RCNN) was proposed to detect cucumber fruits in this scenario. With the rapid development of CNN techniques over the past few years, the detection speed and accuracy of Mask RCNN algorithms are higher than traditional object detection algorithms. Additionally, this paper states that Faster RCNN techniques are available to detect different fruits like peaches, apples, and oranges. This study mainly states how existing art-of-vision techniques can be applied to agricultural robots .

Authors of paper[9] has discussed about the implementation of a robot called 'Vegebot' to harvest iceberg lettuce. Use of CNNs for detect fruits started in late 2000s.Texture based approaches ,using features of near infrared imagers(NIR),use of canny edge filters, use of Adaboost framework, and use of machine learning techniques. They have stated that use of CNNs is the best method to detect lettuce in real time because the lettuce plants and leaves overlap, and the heads are hidden in some scenarios.

III. METHODOLOGY

This section describes the technologies and procedures used in the implementation of this robotic system.

A)Robot structure for Navigation

The navigation structure of the robot is a significant component of this system since it is responsible to hold the robot arm which reaches to the plant. The robotic system which is proposed for the navigation consists with linear bearing rods for both x-axis and y-axis to navigate on horizontal as well as vertical planes to reach every single position of vertical farming greenhouse. It also consists of two cameras to get the distance from the camera to the plant which is useful to map the navigation for the robot. The movement of those linear rods follow the CNC technology which is used in 3D printing machines. It allows to move on the x axis and y axis stably and efficiently by holding the robot arm on it.

B)Plant detection and navigation

For the navigation it is needed to get the accurate position of the plant to move. For that we used two inexpensive commercially available web cameras which are used to get the x, y, z coordinates of the plant where to navigate. This mechanism of usage of two web camera combination is an economical solution instead of using a stereo vision camera. These two cameras are placed certain distance apart from each other and takes one photo of the same object from each camera which is known as the stereovision image. Here, these cameras take the two images of the same object from different point of views. By analyzing the information collected from the above cameras the position and the distance to the plant can be identified.

C)Robot Manipulator Design and Implementation.

Robot manipulator design is one of the major components of the final product, which use to reach towards the crop and get back with the harvested crop. The design of the robot arm is crucial because leaves of lettuce grow as a cluster and therefore the design should be mainly considered to keep minimum impact with the leaves but should have the ability to creep through the leaves to grab the stem. Two methods have used to accomplish previously mentioned tasks were increasing the degree of freedom of robot manipulator and reduce the thickness, bulkiness of the elbows with increasing the strength of them. When increasing the number of degrees of freedom, the total number of independent displacements are also increased. (Degree of freedom is proportional to the independent displacement).

Robot manipulator motion relies on Inverse Kinematics, the process of calculating the angles of each joint to obtain the desired position when the length of each link and the position of the same point in the robot are known. 'Jacobian Matrix' used here to define relationship between joint velocities and end effector.

Denvait – Hartenberg (DH) parameters identified and then transition matrix is generated to move the robot arm in desired position. The robot arm specially designed for hydroponic vertical farming greenhouse with using lightweight material and the low cost. The optimal design and the degree of freedom helps to keep the minimum impact with lettuce leaves and light weighted aid to easy move vertically and horizontally.

Fig. 1. Design of the robot arm.

D)Plant Growth Monitoring Process.

Every plant should be accomplished different growing stages to get the healthy harvest with the minimum time requirement. The growth monitored and compared with the ideal plant in different stages hence could be check whether the plant grown or not in expected level and countermeasures could be taken such as increasing the level of nutrients or controlling environmental facts.

Clear photograph of the crop is captured by the camera mounted on robot manipulator. To detect the only area covered by the crop, color-based segmentation method is used. Green color pixels should be identified in noise removed images to determine the area covered by the grown lettuce leaves. To accomplish the task, RGB image converted in to HSV (Hue, Saturation, Value) format to detach image luminance from color information.

Next, Defined the threshold values for lower (24,40,22) and upper (85,255,255) color ranges which varies color of typical lettuce leaves. Then the area consists of the color range that has defined previously is separated and largest contour (Closed area) is detected.

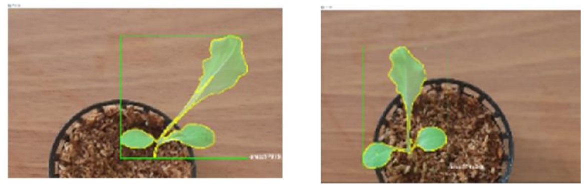


Fig. 2. Original RGB Lettuce images.

Fig. 3. Masked Lettuce Images.

At the beginning it is needed to have an area known image and their total number of pixels. Then must calculate the number of pixels consist in one unit of area using the below mentioned equation. (Assuming lettuce are placed in a fixed distance from the camera in entire process).

$$Area\ covered\ in\ 1\ pixel = \frac{Area\ of\ the\ known\ image\ (mm^2)}{Pixels\ of\ the\ known\ image}$$

The area covered in one pixel is identified and therefore, the exact covered area of the real lettuce leaves able to be calculated through the mentioned equation.

$$Area\ of\ Real\ Lettuce\ Plant = A \times P$$

A – Area covered in 1 pixel(mm^2)
P – Pixels in real lettuce image(pixels)

E.Real-time crops and disease detection

Real-time detection of lettuce is done accordingly to identify the lettuce in good condition which is ready to harvest and to identify different types of diseases such as bacterial, fungal, and viral diseases that are primarily present in lettuce. A camera is mounted on the robot manipulator. Deep learning techniques are used to create the algorithms for crops and disease detection using Convolutional Neural Network (CNN) techniques. The color, shape and texture of the leaves are used to create the algorithm.

Keras and Tenserflow are the open-source libraries used for the CNN training process which can handle high-level computations. In addition, OpenCV, NumPy, Scikit-learn are the external modules used. MobileNetV2 is the neural network architecture used in this scenario, which is a lightweight, low-latency and a low-power model.

1. Preparing the data set.

The images of lettuce crops were taken with a digital camera under normal lighting conditions with image stabilization and the magnification was maintained at 1:1.All the images are taken in RGB(Red, Green, Blue) format. Total of 2150 lettuce images are included where 80% is used for training and 20% for testing respectively. Table 1 shows the lettuce types used in this data set.

No	Lettuce type	Training	Testing	Total
1	Good Quality	280	170	350
2	Bad quality	280	170	350
3	Viral	320	80	400
4	Fungal	280	170	350
5	Bacterial	304	76	380
6	Healthy	256	64	320

TABLE 1 . LETTUCE IMAGE CATAGORIES.

2. Image augmentation.

To increase the number of images in data set, image augmentation techniques was used, and higher number of images were obtained. One image is taken, and it is rotated, shifted, flipped, and zoomed in the given range of values to obtain a new set of images.

Fig. 4. Good quality Lettuce.

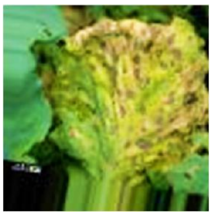


Fig. 5. Fungal Lettuce.

3. Data set pre-processing.

Some images of the dataset are of different sizes due to the factors affected during the time which photos were taken.The images needed to be resized to get the same size for all images and here the image size was changed to 100 by 100 pixels with the use of image scaling techniques. All the lettuce images in the dataset were normalized inorder to convert them into RGB pixel values in range [0 ,1].

For the real time crop detection, training images were stored according to the category and there were two catagories of images as good qualty and bad quality lettuce images.For the disease detection , there were four types of catagories as viral,bacterial,fungal and healthy lettuce.

4. CNN Training.

For the real time fruit detection, MobileNetV2 neural network architecture is used.It is a very effective feature exatrctor for object detection and segmentation.This is 35% accurate than previous VI model.

First, the saved data.npy and target.npy files were loaded and 20% of the dataset utilized to testing and 80% for the training. This is trained to 50 epochs . CNN was able to provide 0.9842 of validation accuracy at the 41st epoch, therefore it was taken as the best model for further predictions. All the model files generated with a higher accuracy were saved in.

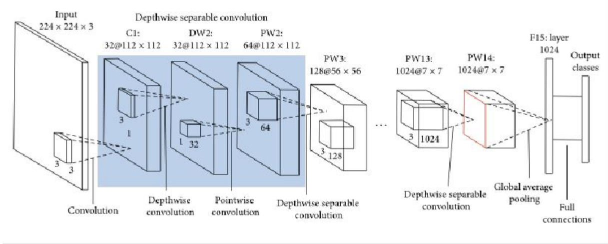


Fig. 6. MobileNetV2 Neural Network Architecture.

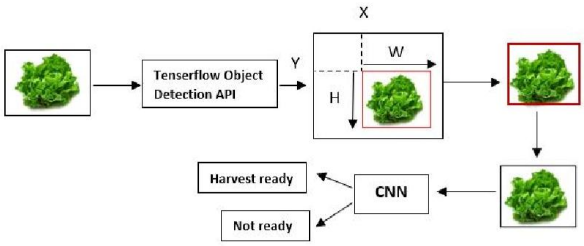


Fig. 7. Process of training CNN.

5. Testing.

Out of the models generated during the training, the best trained model is used with minimum loss and used test images to load images. First tested with test images and the accuracy was 98.22% for the real time fruit detection and 98.19% for the disease detection .Finally this was tested with real time data by taking a video input from camera.

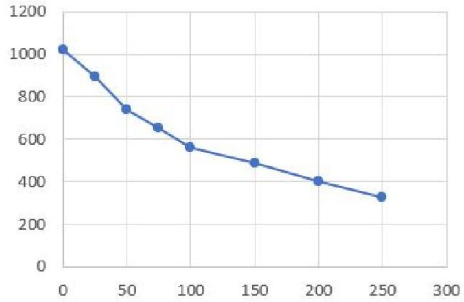
Fig. 8. Good quality Lettuce.

Fig. 9. Fungal Lettuce.

F.Implementation of gripper

The design of the end effector is described in this section. It consists of a smooth gripper that is attached to the manipulator that can lift the lettuce plant smoothly without damaging it.A force sensitive resistor(FSR) is mounted at the end of the gripper and differrent force values were taken at the time of harvesting lettuce.

The force snesitive sensor gives a reading between 0 and 1023 which is a 10 bit value and inoder to convert that value into Force in Newtons(N) ,a calibration method was used.Different weights were taken and calibrated to obtain the relevant force value in Newtons as shown in the following graph.Then this sensor was mounted at the end of the gripper and the force value which causes minimum damage to the lettuce crops was recorded.



GRAPH 1. CALIBRATION OF FSR402 SENSOR

The movement of mechanical claws of the gripper is controlled via the servo motors according to the value of the above reading.These lettuce plants are grown in a hydroponics medium where the plant floats on the solution which makes it easier for the end effector smoothly to lift the plant.

IV. RESULTS AND DISCUSSION

A. Plant position detetction

In the Fig.10 it represents two color video frames taken from the two cameras and their black and white masks. In both frames it shows the detected x, y, z coordinates of the position in millimeters. OpenCV image processing has been used to identify the positions of plants.

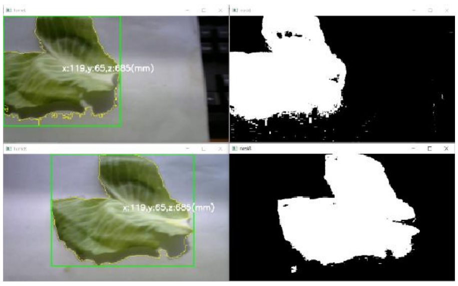


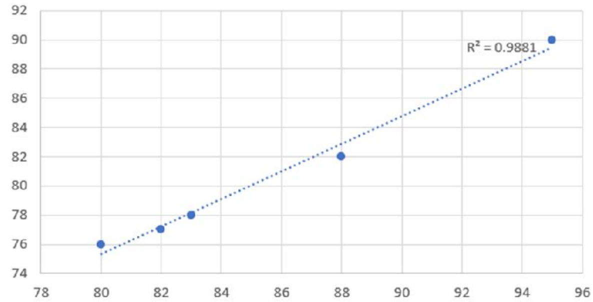
Fig. 10. Lettuce leaf position.

B. Accuracy of area covered by lettuce leaves.(Area generated by algorithm)

Actual Area of lettuce leaves (mm^2)	Area generated by algorithm (mm^2)
80	76
88	82
95	90
82	77
83	78

TABLE 2 . AREA COVERED BY LETTUCE LEAVES.

In here, 0.9881 is the generated R2 value. This value indicates the accuracy of area generated by algorithm. The accuracy increases when the value of R2 gets closer to 1.



GRAPH 2. ACCURACY OF AREA COVERED BY LETTUCE LEAVES.

.

C. Training the CNN

Validation accuracy and validation loss of each epoch were recorded in the graphs as shown in Fig.10 and Fig11.As the second approach CNN was trained using 500 images from each class.50 epochs were executed while the accuracy was 0.9860 and loss of 0.0447.

Accuracy	Val.Accuracy	Loss	Val.Loss
0.9860	0.8324	0.0447	0.7628
Precision	Recall	F1-score	Support
0.82	0.82	0.82	179

TABLE 3 . ACCURACY VALUES OF CNN

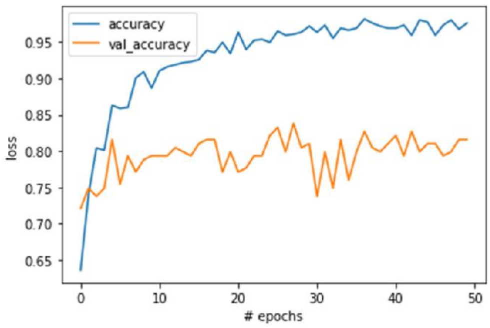


Fig. 11. Training and validation Accuracy.

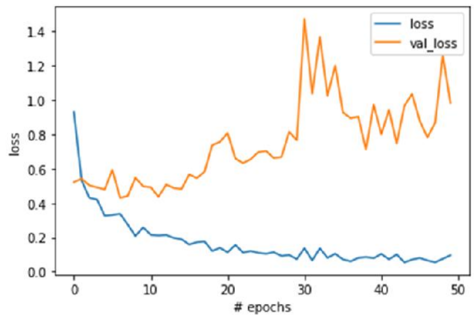


Fig. 12. Training and Validation Loss.

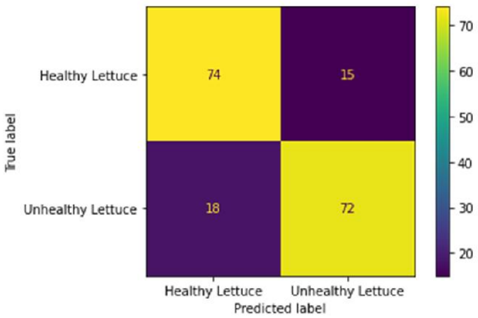


Fig. 13. Confusion Matrix for lettuce harvesting.

V. CONCLUSION

This research is mainly focused on the robotic implementation in a vertical farming greenhouse which has a navigation mechanism, robot manipulator and end effector which helps in crop harvesting and disease detection. The above mentioned system can specially can be used on lettuce crops cultivated in hydroponics medium.

A camera mounted on a robot can be used to capture images of the leaves to discover the symptoms, and also the stereo vision camera setup is used to identify the location of the plant for the navigation. Images are pre-processed once they have been acquired. Deep learning algorithms can be used to forecast the disease after accumulating the symptoms.

As future developments, this project can be expanded to include the environment controlling system which can be used to collect environment factors such as humidity and temperature levels in the plants. As well as the latest technologies can be included for this project as future developments. In the future developments the system can be enhanced to examine more than three exact plant diseases which is implemented in the current system.

VI . REFERANCES

[1] B. T. Kurt Benke, "Future food production systems : vertical farming and controlled environment agriculture.," Sustainability : Science , Practise and Policy, pp. 13-26, 20 November 2017.

[2] R. N. S. P. D. S. K. W. A. Sandunika Fernando, "Intelligent Disease Detection System for Greenhouse with a Robotic Monitoring System," pp. 204-209, February 2021.

[3] A. Yeshmukhametov, K. Koganezawa, Z. Buribayev and Y. Amirgaliyev, "Development of Continuum Robot Arm and Gripper for Harvesting Cherry Tomatoes," 2019.

[4] S. T. William Marchant, "Robotic Implementation to Automate a Vertial Farm System," 30st Florida Conference on Recent Advances in Robotics, 11 May 2017.

[5] L. M. S. S. J. I.Pahole. [Online]. Available: I. Pahole, L. Rataj, M. Ficko, S. Klancnik, S. Brezovnik, M. Brezocnik and J. Balic, "Construction and evaluation of lowcost table CNC milling machine", Scientific Bulletin, Series C: Mehcanics, Tribology, Machine Manufacturing Technology, vol., pp. 1 -7,. [Accessed 03 september 2021].

[6] [Online].Available: https://ieeexplore.ieee.org/document/8679123. [Accessed 03 september 2021].

[7] https://www.researchgate.net/publication/341480005_Designing_of_CNC_Based_Agricultural_Robot_with_a_Novel_Tomato_Harvesting_Continuum_Manipulator_Tool.

[8] D. Z. W. J. W. J. C. R. A. Y. XIAOYANG LIU, "Cucumber Fruits Detection in Greenhouses Based on Instance Segmentation," Wuyishan,China, 2019.

[9] J. H. Y. l. Simron Birrel, "A field-tested robotic harvesting system for iceberg lettuce," United Kingdom, March 13th 2019.

[10] H. Masuzawa, J. Miura and S. Oishi, "Development of a mobile robot for harvest support in greenhouse horticulture — Person following and mapping," 2017 IEEE/SICE International Symposium on System Integration (SII), 2017, pp. 541-546, doi: 10.1109/SII.2017.8279277.

[11] Tharindu Dharmasena, Rajitha de Silva, Nimsiri Abhayasingha, and Pradeep Abeygunawardhana. Autonomous cloud robotic system for smart agriculture. In 2019 Moratuwa Engineering Research Conference (MERCon), pages 388–393. IEEE, 2019.

[12] T. Dharmasena and P. Abeygunawardhana, "Design and Implementation of an Autonomous Indoor Surveillance Robot based on Raspberry Pi," 2019 International Conference on Advancements in Computing (ICAC), 2019, pp. 244-248, doi: 10.1109/ICAC49085.2019.9103399.