ROBOT BASED AUTOMATION OF VERTICAL FARMING

Project Report

Submitted in partial fulfillment of the requirements for the award of the degree of

Bachelor of Technology
in
Mechanical Engineering

by

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CERTIFICATE

This is to certify that the report entitled "**ROBOT BASED AUTOMATION OF VERTICAL FARMING**" is a bonafide record of the **Project** done by **AKONDI SAI MANOJ** (*Roll No*.: **B180161ME**), **KURAGANTI VEDANTHAM**(*Roll No*.: **B180473ME**), **MAMIDI THEJONATH**(*Roll No*.: **B180129ME**) and **POOLA ROHITH** (*Roll No*.: **B180712ME**) under our supervision, in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Mechanical Engineering** from **National Institute of Technology Calicut**, and this work has not been submitted elsewhere for the award of a degree.

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ABSTRACT

Agriculture is one of the most important sectors in the Indian economy. In agriculture sector vertical farming involves growing crops in a controlled environment which aims to optimize the plant growth and implement soilless farming techniques which is space and water efficient. Hydroponics uses 90% less water for farming compared to the traditional agriculture. Implementation of robots instead of human beings in agriculture will be very useful as it reduces human effort and labour in farming to a great extent.

The project focuses on building a prototype of a robot based automated vertical farm by developing a serial mobile manipulator with a multi-purpose end effector for planting and harvesting of the crops and development of a lift to enable the manipulator to reach higher stacks. In addition to the development of a robotic manipulator, another objective is to completely automate the farming activities such as planting, inspection and harvesting with minimum or zero human intervention using computer vision techniques and deep learning algorithms.

CONTENTS

LIST OF ABBREVIATIONS

DOF	Degrees of Freedom
YOLO	You Only Look Once
MAP	Mean Average Precision
COCO	Common Objects in Context

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The world population is growing at an alarming rate. According to the world census, the world population will rise from 7.3 billion today to 9.3 billion by 2050. Farmers will face serious pressure to keep up with demand. To this problem of ever-growing population, vertical farming emerged as a powerful solution. In implementing and maintaining the vertical farms there is a huge requirement of labour and skilled workers in some domains which will be hard for investing as well as maintaining such huge workers and work flow. Solution for this problem is automation of the vertical farms with robots which is the prior idea of our project. This minimizes the labour to a great extent, increases accuracy and precision of tasks to be performed while farming, and also increases productivity as robots can work the entire time. We further innovate this idea by including hydroponics to vertical farming. Hydroponics is an alternative and best replacement to the soil in agriculture.

1.2 Significance & Motivation

Vertical farming is the practice of growing crops in vertically stacked layers. Usually, vertical farming involves a growing crop in a controlled environment which aims to optimize the plant growth and soilless farming techniques such as hydroponics, aquaponics and aeroponics. As of 2020, there is the equivalent of 30ha (74 acres) of operational vertical farming in the world. Current applications of vertical farming coupled with other state-of-the-art technologies, such as specialized LED lights, have resulted in over 10 times the crop yield than would receive through traditional farming methods.

Fig 1.1: Vertical farm – Hydroponics

Fig 1.2: Vertical Farm – Aeroponics

The idea of using Hydroponics instead of soil is a major breakthrough in the field of agriculture. In traditional farming there are a lot of disadvantages such as losing the fertility and nutrient content in the soil, water wastage, uncontrollable environment conditions etc. Recent statistics have proved that 67% of water used in agriculture is going waste through evaporation and run outs which will be a major concern for water scarcity in future. But Hydroponics use 90% less water for farming and which is 10 times lesser than water used in traditional agriculture.

1.3 OUTLINE OF THE REPORT

The current chapter explains the need for efficient farming techniques and automation of the same. In the second chapter, literature review is carried out by focusing on the previous works done. In the same chapter, a research gap is found by listing the advantages and limitations of each literature. Third chapter describes various conceptual models of manipulators and advantages and disadvantages of the same. Fourth chapter includes details of simulations that are carried out and an object detection algorithm trained to detect tomatoes and apples. Final chapter discusses conclusions and future scope.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

The concept of vertical farming was first proposed in 1999 by Prof Dickson Despommier. With an exponentially growing population, the demand for food is increasing at alarming rates. To address this problem, efficient farming techniques are being invented. Vertical farming is one such method which can produce large quantities of crops with minimum space, water and resources. Although vertical farming is efficient, the manpower required is significantly high, which triggered the need for robot-based automation in vertical farming.

2.2 PREVIOUS WORKS

The main purpose of the project is to automate vertical farming by implementing hydroponics. A preliminary literature review shows that many recent studies and innovations are primarily focused on vertical farming implementation, hydroponics usage and their individual automation.

There have been many innovative works in the same area, which includes, 'System for indoor plant cultivation' where a cabinet is designed for farming which can maintain all the growth conditions of the plant, but the farming part is not automated in this system [1]. This project partially includes the above-mentioned idea of inspecting and maintaining the growth of plants in an indoor
environment.

'Domestic Autonomous Vertical Farm that is movable in stackable units',
[2] This patented project focused on developing portable equipment for an autonomous vertical farm which can be easily installed. The automation includes only the environment conditioning part like lighting, humidity etc., but it doesn't completely automate the farming such as planting and harvesting of the crops.

‘Indoor Hydroponics systems’, [3] This innovation includes the idea of vertical farming and hydroponics. The project is to develop a closed cabinet which controls and monitors the growth of the plants, environment conditions and is nurtured by hydroponics. It can be closely related to the similar work [4], Hydroponic Plant grow Cabinet. All the recent works on automation of vertical farming focused on automating the growth monitoring and conditioning.

The recent studies evident that vertical farming will be the future of agriculture. The research work [5] has mentioned the feasibility and main advantages of vertical farming over conventional agriculture which is one of the key motivations for our innovation.

‘Robotic Implementation to Automate a Vertical Farm System’, [6] This research work mounted a cartesian manipulator on each vertical stack and used stereo vision for depth estimation. To maximize the production, they have introduced algorithms called “harvesting algorithm” and “planting algorithm” which are run at specific time intervals.

Our idea includes using the suitable features of the existing innovations and further innovating to implement the complete automation of vertical farming.

2.3 RESEARCH GAPS

Based on the literature review, the limitations are identified which coined the research gap.

- Traditional farming consumes lot of space and water
- No related prior works are reported on robot based automation of vertical farming to the best of the author's knowledge.
- Most of the recent works focused only on the plant growth monitoring and conditioning.
- Complete automation of vertical farming which involves planting, inspection, harvesting etc., are not implemented till date as per the literature

2.4 OBJECTIVES

Main objective is to develop an Autonomous 4 Degrees of Freedom (DOF) mobile robotic manipulator for vertical farming which includes

- Designing of multi-purpose end effectors for planting and harvesting.
- Implementing lift for accessing upper stacks.
- Fabrication of optimized end effectors and the manipulator.
- Control and automation of the mobile manipulator
- Minimizing human intervention in farming.
- Maintaining a controlled environment.

CHAPTER 3
CONCEPTUAL DESIGNS

3.1 INTRODUCTION

Based on the research gaps found, an effective way of automating the vertical farming could be carried out incorporating an autonomous 4 DOF mobile manipulator, multipurpose end-effectors and lift for reaching upper stacks of the vertical farm, Different conceptual designs and important parameters were determined for the conceptual scoring.

3.2 MANIPULATOR

A standard 4 DOF manipulator is selected for reference and modified the dimensions and other construction parameters to meet the requirements of the objectives to perform planting, inspection and harvesting tasks inside a vertical farm. The manipulator is attached to a mobile base with mecanum wheels for ease and precise locomotion of the robot in the farming environment. Two models of the manipulator are designed, one with indirect power transmission using gears and pulley-belt drive and the other with direct power transfer to the corresponding links

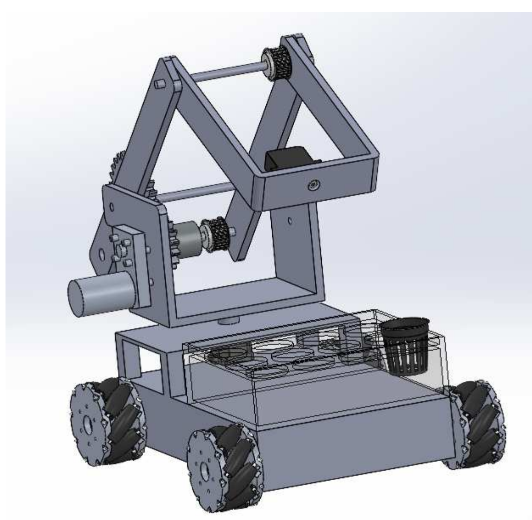


Fig 3.1: Manipulator_1

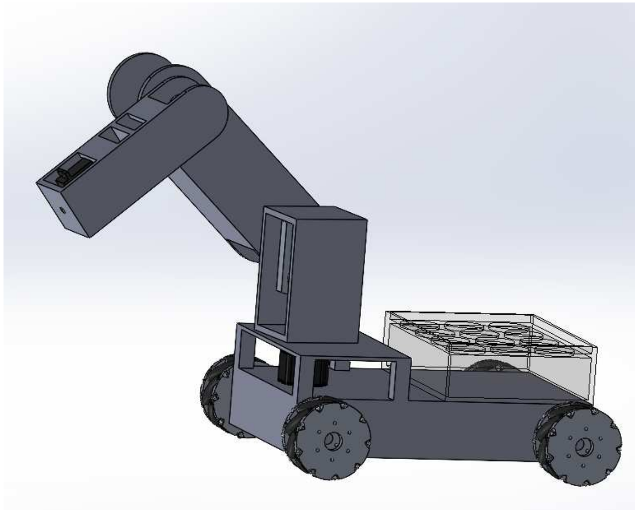


Fig 3.2: Manipulator_2

3.3 END EFFECTORS

The two important tasks of the end-effector are planting and harvesting. For planting and holding the vegetables four grippers are designed. Considering various contributing factors such as feasibility, stability, accuracy and repeatability, ease of manufacturing, cost of manufacturing etc., concept scoring was made for the four gripper models and best two models are selected.

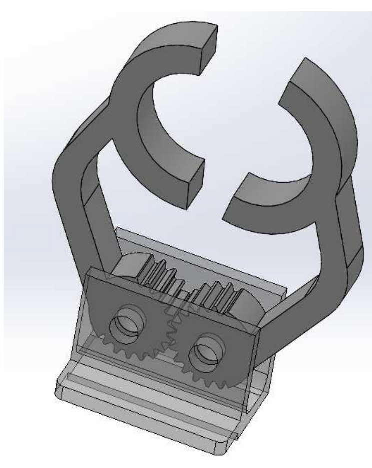


Fig 3.3: Gripper_1

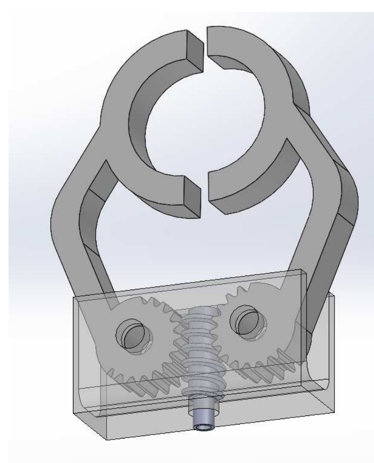


Fig 3.4: Gripper_2

The fig3.3 (gripper1) and fig3.4 (gripper2) are specifically designed for holding the cylindrical cup of the nursed plant during planting. The inner shape is designed such that it can precisely accommodate the cup. The difference between the two grippers is the gear transmission. In gripper1 servo motor will be attached directly to the finger of the gripper where as in gripper2 the motor is attached at the back of the worm gear.

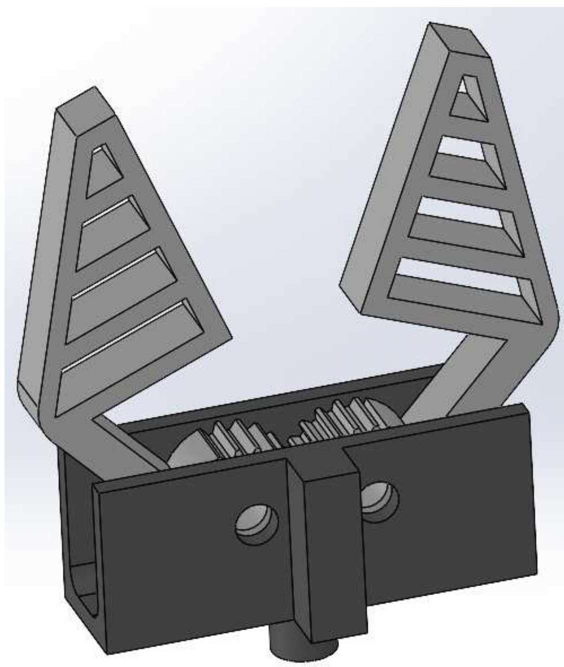


Fig 3.5: Fin Gripper

The fig3.5 is the design of fin gripper and it can be used to hold both the planting cups and vegetables. The finger of this gripper is called as 'Fin' and the fin is made of an elastic material such that its inner surface is adaptable which provides large grip surface and will be safe to hold vegetables. It is actuated by a servo motor attached to one of the fins.

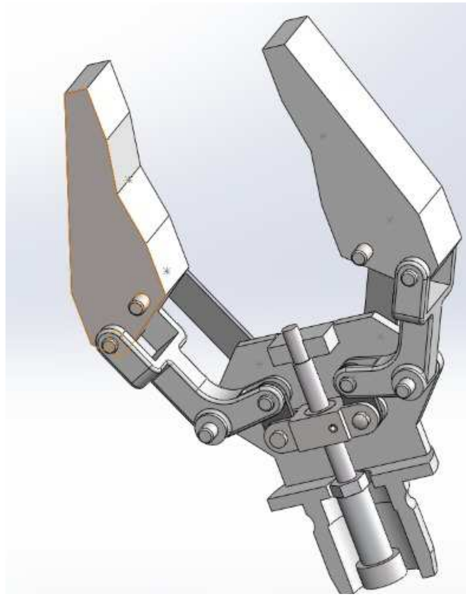


Fig 3.6: Gripper_3

The Gripper_3 (fig3.6) is the designed to be actuated with a small lead screw mechanism. The advantage of the gripper4 is that it is actuated by small lead screw and nut mechanism which has good precision in the distance control during actuation.

		Gripper			
Attributes	**Weightage%**	**Two Fingered**	**Two Fingered**	**Two Fingered**	**Fin**
		Spur	Worm & Spur	Lead screw	Adaptable
Payload Capacity	20	3.5	3.5	3.5	3
Stability	20	2.5	3	3	3.5
Feasibility	20	3.5	3.5	3.5	4
Accuracy and Repeatability	20	2.5	2.5	3	3.5
Ease of Manufacture	10	3.5	3	3	3.5
Costs of Manufacture	10	3	2.5	2.5	3
Total	100	3.05	3.05	3.15	3.45
Rank		**3**	**3**	**2**	**1**

Table 3.1: Concept Scoring of Grippers

From the concept scoring the best two grippers are selected to design end-effectors for harvesting. Different mechanisms are designed to perform harvesting like a blade with three sharp wings, elliptical shaped disc with cutting edges at one the major diameter's end and a trimmer mechanism which will be incorporated along with the gripper which is used to grip the vegetables while one of the cutting mechanisms is implemented to cut the node of the product.

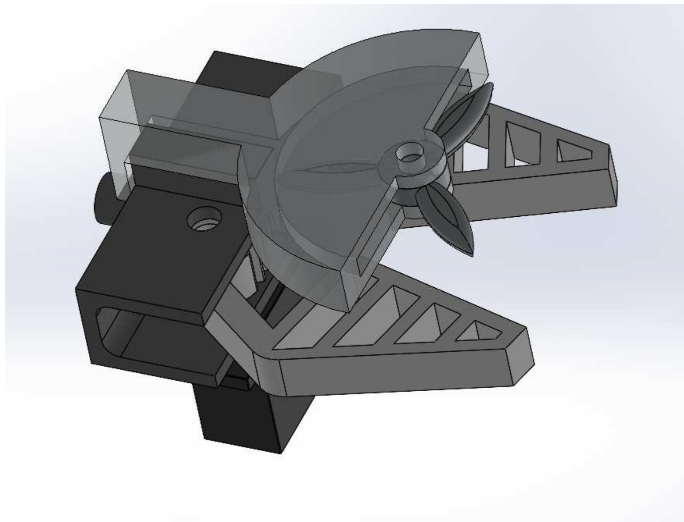


Fig 3.7: Blade Cutter mechanism

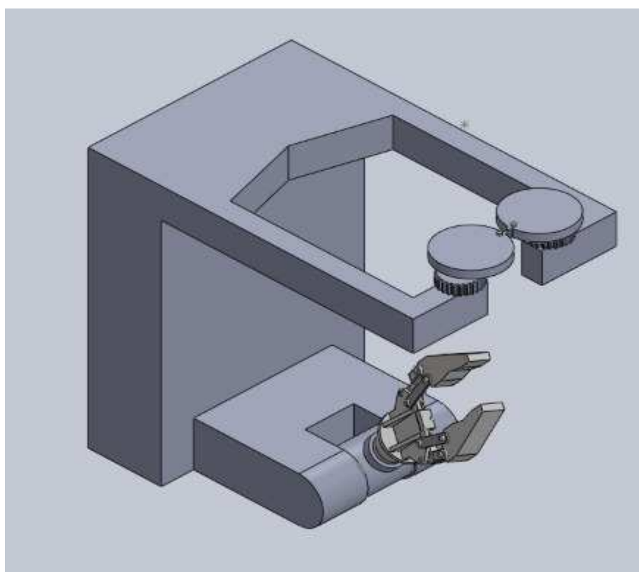


Fig3.8: Disc Cutter mechanism

3.4 LIFT

To take the manipulator for upper and lower stacks in a vertical farm a lift mechanism is incorporated. Different possible mechanisms were designed using lead screws, counter weight and worm-spur gear. Finally considering various contributing factors the worm-spur gear mechanism is selected for the lift.

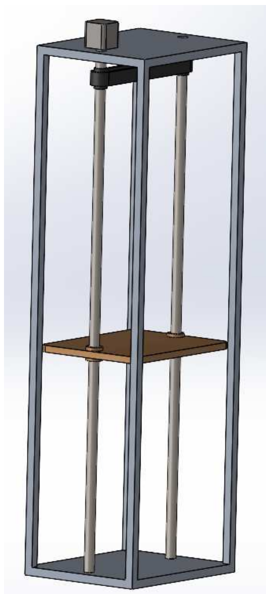


Fig3.9: Lead Screws

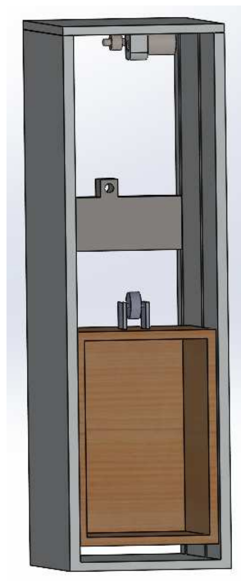


Fig3.10: Counter Weight

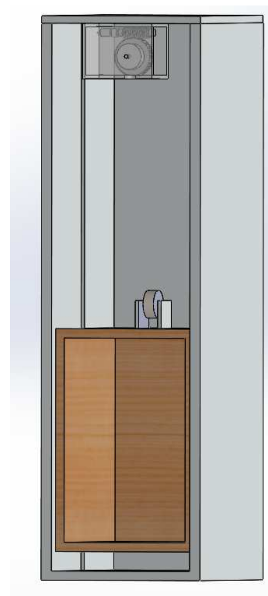


Fig3.11: Worm – Spur gear

Lift for Manipulator				
Attributes	**Weightage%**	**Counter Weight**	**Lead Screws**	**Worm and Spur gear**
Payload Capacity	20	3.5	3	3
Stability	20	3.5	4	3.5
Feasibility	20	3	3.5	3.5
Accuracy and Repeatability	20	3	3	3.5
Ease of Manufacture	10	3	3	3.5
Costs of Manufacture	10	2.5	2.5	3
Total	100	3.15	3.25	3.35
Rank		**3**	**2**	**1**

Table 3.2 Concept Scoring for Lift

3.5 VERTICAL FARM

A two stacked vertical farm is designed for developing a prototype of the scaled environment of a vertical farm. In a single stack 4 rows were incorporated for growing crops and paths are given in between the rows for locomotion of the mobile manipulator.

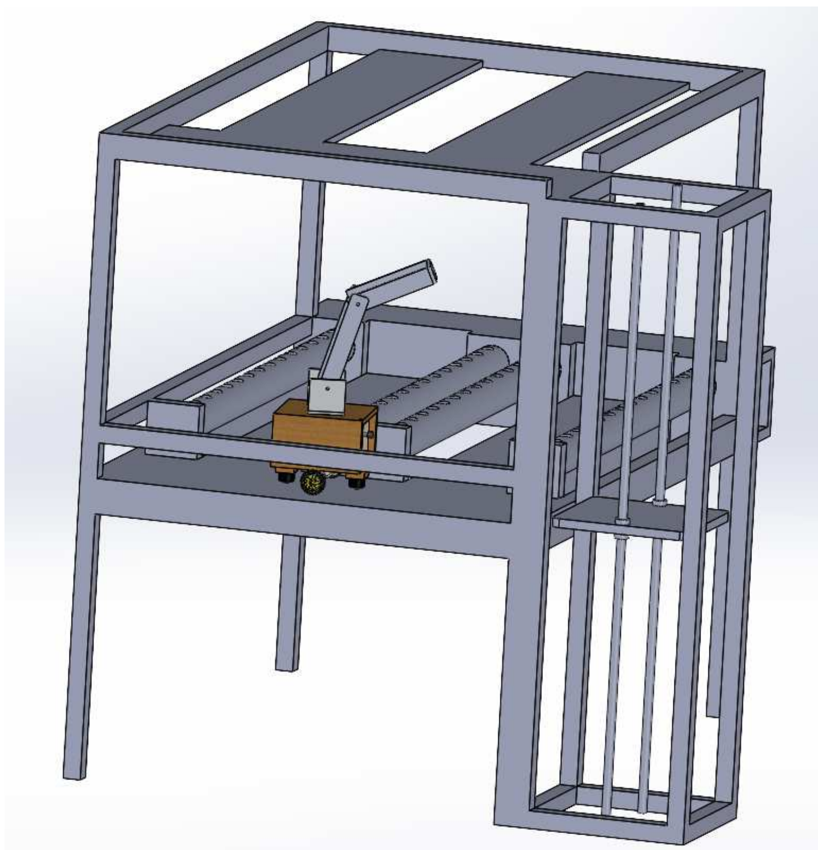


Fig3.12: Vertical Farm

CHAPTER 4

SIMULATION AND ALGORITHMS

4.1 SIMULATION IN VIRTUAL ENVIRONMENT

Controller is responsible for driving the robot in the desired trajectory. Along with the trajectory, it is also responsible for performing required tasks. Before directly writing a controller and deploying it in real time, a virtual environment is created in a software called “webots” to test the controller. Webots is a robotic simulation software which can simulate the physics and accepts wide range of programming languages such as C, C++, C#, Python, Java, etc.

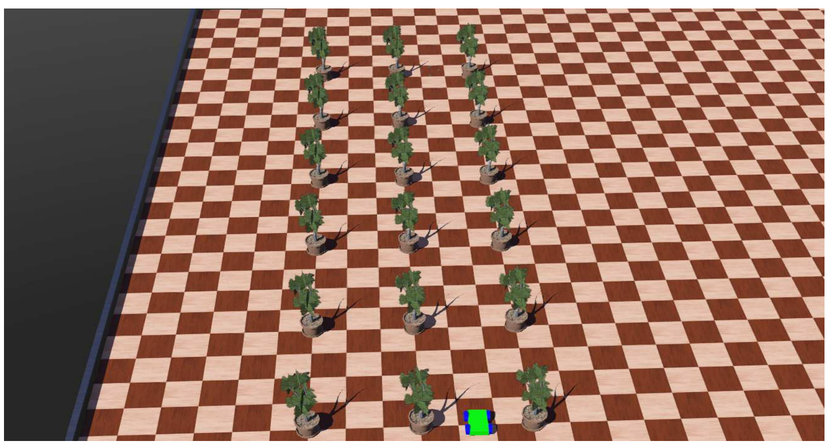
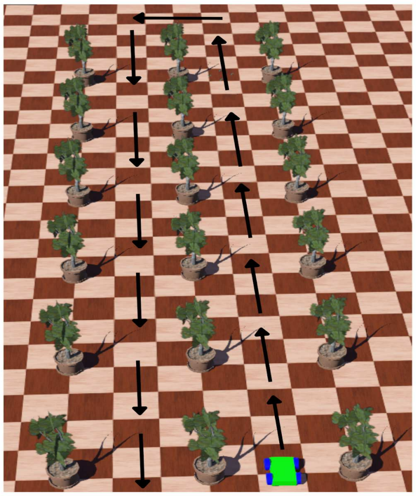


Fig4.1: Farming Virtual Environment

The virtual environment consists of three parallel rows of trees having an aisle between each two of them as shown in the below fig 4.1. The distance between the rows is set as 1.5 units and plants in each row are separated at a distance of 2 units. A small temporary prototype of the mobile base (excluding the manipulator) is made to carry out the simulation.



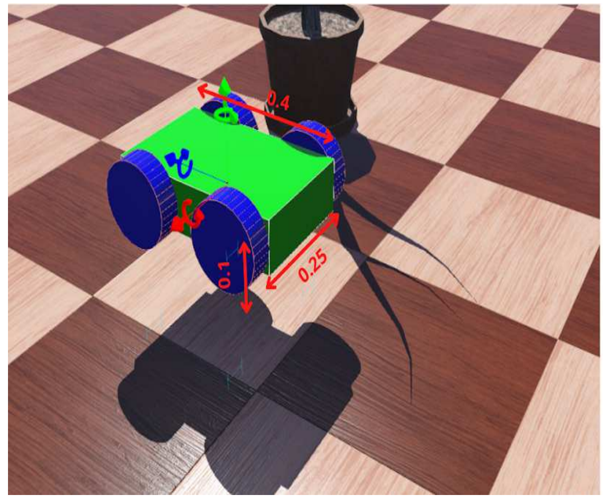


Fig4.2: Path Between Rows

Fig4.3: Mobile base

The robot is expected to take the path shown with black arrows in fig 4.2. At each plant, it should stop for a few moments allowing the manipulator to inspect the plant. At the end of the first aisle, the robot has to take a turn and enter the second aisle. A similar inspection scheme will be carried out for second and third rows as well.

Python language is chosen for controller programming as it comes handy with machine learning frameworks which can be used for further development of the controller.

4.2 OBJECT DETECTION ALGORITHM

The task of object detection is to identify and localize a set of objects from a given input image. The algorithm used is yolov5 which is a recent deep learning model [8].

The model is trained on 817 images, out of which 510 are apples and the rest are tomatoes. It's a standard practice in the field of machine learning, to transfer the weights of the model that are trained on one dataset as a starting point for another dataset. This procedure is called "transfer learning" [9]. The model is pretrained on the "COCO" dataset (which contains various objects that one can encounter in daily life). The pretrained model is finetuned on the tomatoes and apples dataset.

Two variants of the model are trained, the first one is trained with the first 10 layers frozen whereas the later one is trained fully. Better mAP, precision and recall metrics are noticed for the second model. Comparison of both the models is shown in Table 4.1. Google colab's GPU is utilized for training purposes. Pytorch framework is used to code the architecture and carry out the experiments.

model	**mAP@0.5**	**mAP@0.9**
YoloV5(first 10 layers frozen)	0.78261	0.40897
YoloV5(all layers are trainable)	***0.823***	***0.457***

Table 4.1: Comparison of yolov5 with and without freezing layers

The model has achieved its best mAP@0.5 of 0.823 in 35 epochs. Rest of the metrics are shown in Table 4.2. The training has taken around 1.5 hours on colab's GPU. Since, the model has shown no improvement after 35 epochs (which is evident from mAP@0.5 curve shown in fig 4.5, the training was stopped at the 35th epoch and best weights are saved. Standard hyperparameters which are mentioned in Table 4.3 are used while training the model. Results are shown in fig 4.6 and fig 4.7.

Metrics	Values
mAP@0.5	0.823
mAP@0.9	0.457
Precision	0.852
Recall	0.78

Table 4.2: Metrics of best model computed on 124 images

Hyperparameters	values
Image size	640
Learning rate	0.001
Batch Size	16
No of Images	510(apples)+ 307(tomatoes) = 817 images
Test Images	124

Table 4.3: Hyper Parameters used while training

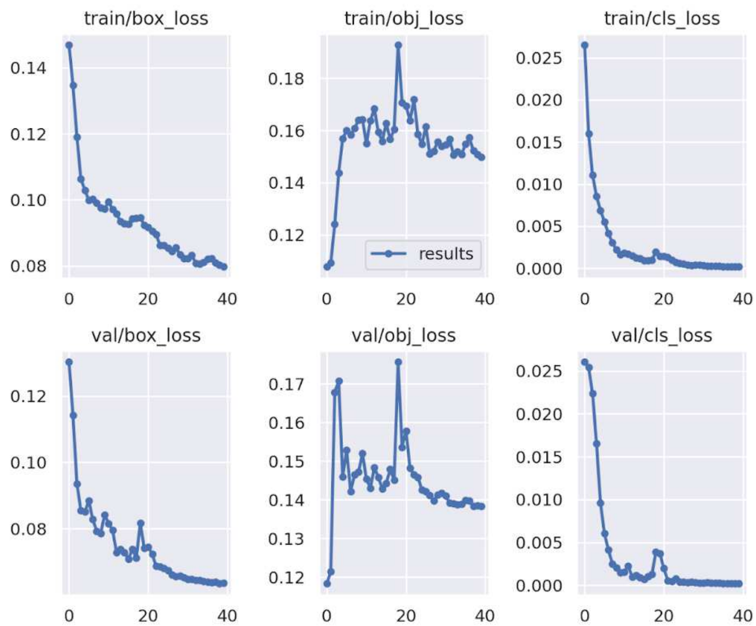


fig 4.4: loss vs epoch

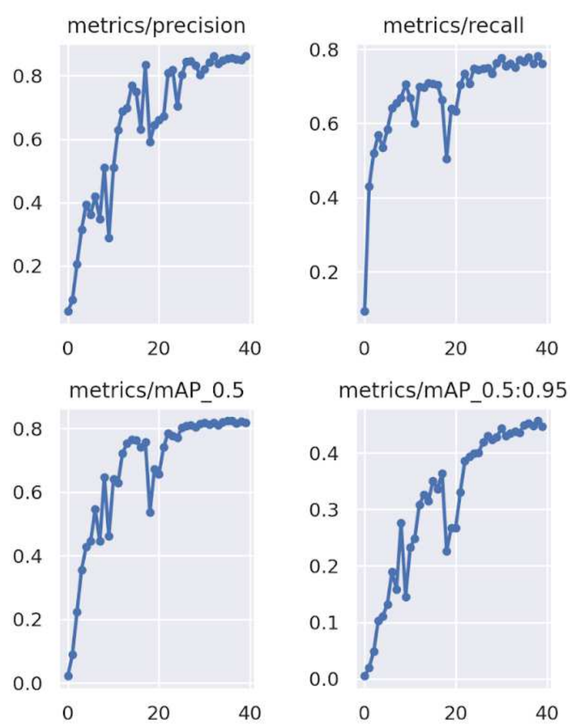


fig4.5: mAP vs epochs

(a) (b)

Fig 4.6: Detection of tomatoes

(a) (b)

Fig 4.7: Detection of apples

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSIONS

A standard 4 DOF serial manipulator is selected and modified to meet the requirements. Different multi-purpose end effector models are designed for performing planting and harvesting tasks. A lift mechanism is developed with a worm and spur gear mechanism to take the manipulator for higher stacks.

Simulation of the mobile base of the manipulator in a virtual environment (created in software called "webots") is completed. The controller is written in Python to take halts for inspection and turns wherever necessary. An Object detection algorithm YoloV5 is trained to detect tomatoes and apples which can potentially be used to know the location of a target during real time deployment.

5.2 SCOPE FOR FUTURE WORK

- Performing kinematic simulations of the manipulator
- Development of required AI/ML algorithms and
- Implementation of Reinforcement learning.
- Fabrication of the Robotic manipulator and the vertical farm.
- Control and automation of the robot by implementing developed algorithms in the fabricated model.

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