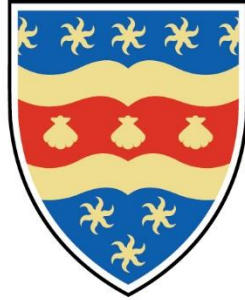


*This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright rests with its author and that no quotation from the thesis and no information derived from it may be published without the author's prior consent.*



# UNIVERSITY OF PLYMOUTH

Robot for harvesting cauliflower, and the cutting of  
cauliflowers

By

Taha Auzeeri

A thesis submitted to the University of Plymouth in partial fulfilment for the  
degree of

**RESEARCH MASTERS**

School of Engineering, Computing and Mathematic

July 2021

## Declaration

At no time during the registration for the degree of Research Masters has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee. Work submitted for this research degree at the University of Plymouth has not formed part of any other degree either at the University of Plymouth or at another establishment.

This is to certify that the candidate, Taha Auzeeri carried out the work submitted herewith

Candidate's Signature:

Taha Auzeeri :

\_\_\_\_\_

Date: 13/05/2021

Supervisor's Signature:

Dr. Swen Gaudi:

\_\_\_\_\_

Date: 13/05/2021

Number of words: 11921

## ABSTRACT

Title: Robot for harvesting cauliflower, and the cutting of cauliflowers

Author : Taha Auzeeri

The human arm bounded by soft tissues and muscles is capable of fast movement with high precision fidelity. And it is soft as it has muscles and other tissue. Nowadays, robots can do many human tasks. Robot arms are also becoming softer, to make them stronger and safer to use around humans while working in real-world environments. In this study, the focus is on a robot for harvesting cauliflower, and the cutting of cauliflowers in particular. The robotic platform is designed to reuse modular robotic components from other crops and/or different cauliflower varieties. The platform has two robot arms with variable-stiffness technology. The first arm is for cutting the cauliflower in its steam. And the second is for picking the cauliflower.

The GummiArm is a 7+1 DOF robot arm and is an open-source project. Here it is used with a cauliflower-specific end effector, which is a cutter designed with 3d printer, while the second arm has a gripping end-effector. The bi-manual configuration allows the separation of grasping and cutting behaviours into separate robot manipulators, enabling flexibility to adapt to different varieties. Here the focus was on the cutting, and on the control of these through the Robot Operating System (ROS). Several experiments were performed with a force-Analysis of the cutting behaviour, during teleoperation, and when using a control exploiting the passive compliance of the GummiArm.

These early experiments with the laboratory platform demonstrate the platform's promise, but also a set of challenges to tackle. This new data can be used to compare human labour performance, develop operational concepts and business plans, and drive future design decisions.

## TABLE OF CONTENTS

<b>ABSTRACT.....</b>	<b>4</b>
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>7</b>
1.1 Semi-mechanical Harvesting: .....	8
1.2 Mechanical Harvesting .....	8
1.3 Research contribution .....	9
1.4 Hardware Used.....	10
1.5 Software Used:.....	10
1.6 Thesis Structure: .....	10
<b>CHAPTER 2. LITERATURE SURVEY .....</b>	<b>11</b>
<b>CHAPTER 3. ROBOT PLATFORM.....</b>	<b>16</b>
3.1 Picking rig.....	16
3.2 Workspace analysis.....	16
3.3 Cutting controller .....	19
3.4 Gummi heavy robot arm .....	20
3.5 software architecture .....	21
<b>CHAPTER 4. EXPERIMENT 1: FORCE ANALYSIS OF CUTTING BEHAVIOUR .....</b>	<b>24</b>
4.1 Introduction.....	24
4.2 Method .....	24
4.2.1 Apparatus .....	24
4.2.2 Protocol.....	25
4.3 Results and discussion .....	25
<b>CHAPTER 5. EXPERIMENT TWO: EXPLOITING PASSIVE COMPLIANCE DURING CUTTING.....</b>	<b>28</b>
5.1 Introduction.....	28
5.2 Method .....	29
5.3 Apparatus .....	29
5.4 Protocol.....	29
5.5 Results and discussion .....	29
5.5.1 force and time of closed loop cutting robot arm .....	29

5.5.2 EE\_trajectory pose of closed loop cutting experiment ..... 35

**CHAPTER 6: General discussion..... 44**

6.1 Difference between teleoperated with joystic mode and closed loop mode ..... 44

6.2 Taking over Farm Labour ..... 44

6.3 Efficiency ..... 45

6.4 Automated broccoli harvester turns to Fanuc ..... 45

6.5 Plant Care..... 47

**CHAPTER 7: CONCLUSION..... 48**

**REFERENCES..... 49**

## CHAPTER 1: INTRODUCTION

Harvesting in general is basically carried out when edible parts of a plant or plants have reached a certain amount of maturity or in simple terms when all the nutrients of plants are developed. The high cost of human labour is the main motivation of this work to build automated systems around the agriculture field; over the past 30 years, a huge range of agriculture robots has been introduced and improved by the time, in this work we will be revealing on the cauliflower harvesting robot. over the past three decades research has been carried out for about 50 systems the harvest e.g., apples, oranges, tomatoes, cucumbers strawberries and melons. The European FP7 project CROPS [41] is developing a modular robotic system for several different tasks (harvesting apples, grapes, sweet peppers and spraying).

Most harvesting operations for Brassica crops are still done by hand, which raises the farmer's costs. Although large, combined harvesters for broccoli and cabbage are available, current technology has several drawbacks. For starters, it will harvest all crops in one section of the field at any time, mature or not, resulting in massive waste. That is, no commercially available selective harvesters are currently available.

Harvesting involves two simple processes:

- Cutting
- Gathering

There are three different methods that are used for harvesting horticultural crops (nuts, vegetables and):

- Manual (Hand) Harvesting
- Semi-mechanical Harvesting
- Mechanical Harvesting

### ***1.1 Manual (Hand) Harvesting:***

It is the traditional harvesting methodology which is most commonly used by farmers to harvest high-value crops such as vegetables, fruits, spices and condiments. This kind of harvesting is popular for fruits that have a large time windows for maturity and they are also popular for fruits that are available for direct consumption [1]. Manual harvesting is selective harvesting as farmers only harvest the fruits or other high-value crops that are ripe. It was found by some researchers that this kind of harvesting is usually preferred to achieve high-quality control and minimize the damage caused while cutting or grasping high-value crops [2]. It is evident that manual harvesting is labour-intensive, resulting in increased cost in overall labour expenses.

So, due to high labour costs and sometimes unavailability of labour force to carry out harvesting semi-mechanical and different mechanical methods are used. Sickle is a hand-held agricultural tool that is used by farmers to harvest different crops and grains. The following figure shows the sickle (is kind of a hook with curved blades for manual harvesting)



Figure 1: hock with curved blades for manual harvesting

### ***1.2 Semi-mechanical Harvesting:***

This kind of harvesting method is used to increase the harvesting efficiency while reducing the harvest cost. The widely adopted semi-mechanical devices are equipped with supporting mechanisms such as Conveyor belts and Vibrating-shakers. In terms of harvested amount, detachment selectivity, and fruit quality after harvest, the semi-mechanical, platform-based harvest aid system performed well. Fruit harvested by semi-mechanical harvesting systems was as good as fruit harvested by hand in some cultivars and maintained good quality in cold storage. The following advantages are provided by the semi-mechanical harvesting system: (1) Increased harvest efficiency when compared to hand harvesting. Workers are not required to position the catch frame beneath the plant, move the air compressor, shake the fruit off the plant, and then handle the fruit collection box [18]. Harvest efficiency is expected to improve as a result of the elimination of these steps. The semi-mechanized harvest method, which used a portable mechanical coffee harvester, resulted in the highest harvest yield and the lowest operating costs. The semi-automated harvest had the most defoliation [19].

### ***1.3 Mechanical Harvesting***

Primary purpose of mechanical harvesting is to reduce the labour costs and to accelerate harvesting, primarily benefitting the large crop commodities. This kind of harvesting thereby helps in using the labour force effectively. Based on type of the fruits and vegetables, different mechanical devices are used for harvesting ensuring that the effects on the harvested fruits and vegetables are kept to bare minimum as possible. The example of commonly used mechanical harvesting includes Limb shaker, canopy shaker, trunk shaker and harvesting robots.

Though some of the mechanical devices exploits the labor force in effective manner, these devices are not able to achieve selective harvesting. Therefore, robotics was introduced to perform



selective harvesting. The robot assisted harvesting also increased the effectiveness whilst keeping the labor cost low compared to traditional(manual) harvesting methods.

This robotic harvesting makes use of cutting-edge computer vision and AI technologies to detect and identify the readiness of the fruits or vegetables, i.e. whether or not they are in the appropriate condition to be harvested. Although, many researchers have made breakthrough achievements in harvesting robots, the research for optimized and crop specific robots are ongoing, especially for harvesting high-value crops.

### ***1.3 Research contribution***

This research aims to demonstrate selective harvesting of cauliflower using Gummi Arm. Gummi Arm is a passive compliant variable stiffness robotic arm developed by researcher Dr Martin Stolen in 2016. The Gummi Arm is modified for the research work, where two passive compliant variable stiffness Gummi Arms were used to perform cutting and grabbing respectively. This thesis is aimed to investigate and achieve the following key milestones:

- Kinematic analysis of Gummi Arm by calculating DH (Denavit-Hartenberg) parameters.
- Performing active tests on different types of cauliflowers using Joystick mechanism.
- Performing passive tests on different types of cauliflowers using automated algorithm/ This also includes the coding of control system to perform selective harvesting.
- Conduct a comparison study by utilising the results from testing(active & passive) to understand the effectiveness, differences and similarities in active and passive tests.
- Derivation of conclusion on the most effective robotic harvesting method from the results, observations and comparison study.

We can list this thesis contribution in the points below.

- We compared two type of cauliflower harvesting closed-loop and teleoperated with joystick.
- Changing the end-effector shape and size to a bigger one to cut the cauliflower in a more accurate way but the weight was more, and it was taking more time.
- In closed-loop we used 2 direction x and y for the cut in future work we can use Z as well for more accurate cut.

For our study purposes we used two types of controllers, one with joystick which needs human interaction and supervision to get the job done, and the second one is closedloop autonomous cutting mimics the first controller action but in autonomous way without human interaction.

To make the comparison fair we needed to make sure that the automated system is harvesting the cauliflower in the same environment as the teleoperated system, other research has used different phrases for this action like passive, active, semi-manual, and autonomous.

Researchers in [17] Compared harvesting using three tractors for autonomous pal moss harvesting, they designed the system to mimic manual harvesting operation and maintain safe working environment, to do that they equipped each tractor with a build-on automation package, in includes positioning, planning and control, also coordinates and perception system, to detect obstacles and report changes, in the manual harvesting a team leader controls the tractor by communicating via

wire, or radio connections, the team leader is the main decision maker and is responsible for speed and the process of achieving success.

The automated system should make sure that they work at the same environment as the manual tractors to be able to make fair comparison, for this study the automated harvesting performed good but the manual one was faster, although that the manual one was faster than the autonomous way, we are switching to close-loop autonomous harvesting to save labour high cost and make the working environment safer.

#### ***1.4 Hardware Used***

- The Hardware setup primarily consists of two dexterous passive compliant variable stiffness robotic arms, mounted on an inverted-U wheel. Each arm comprises of three parts; shoulder, upper arm and lower arm. The End effector is attached to one end of lower arm.
- One robotic arm is used to perform cutting operation and other robotic arm is used to perform grasping operation. As the agonist-antagonist method is chosen to move the robotic arm (Similar to the human hand with flexible tendons) by employing a pulley system driven by servo motors. The servo motors enabled the electric impulsive operation of the robotic arm in agonist-antagonist manner. The optimised grasping operation is achieved by integrating a force measurement sensor, that regulates the overall grasping mechanism.

#### ***1.5 Software Used:***

Software system is implemented on Ubuntu 16.04 domain and ROS (Robot Operating System) platform is configured as development platform. Python programming language is used for the software development and analysis of robotic arm workspace is carried in MATLAB. The passive tests for evaluating the pruning and grasping operation is done using Flex BE software.

#### ***1.6 Thesis Structure:***

The second Chapter of this thesis discusses the current research on selective harvesting of high-value crops using robotics and recent trends for utilising robotics to facilitate selective harvesting.

The configuration of the robot used for carrying out the research and the results obtained via the robot workspace analysis are discussed in chapter 3 of this report.

Chapter 4 offers detailed explanation about the active and passive experiments carried out to determine the most efficient setup using the the results obtained from the experiment.

Conclusions and future exploitation with recommendations are presented in Chapter 5.

## CHAPTER 2. LITERATURE SURVEY

Collecting is counted as one of the most important rather difficult at the same time to build the road and the job of applicants – whistleblowers [20]. High-quality plants are mainly cut, for example organic products, vegetables, decorations, packaging and flavors [21]. The use of special harvesting robots needs to be considered, if cultivation is required to be carried out with great care. It is common and obvious that the traditional way of farming consumes manual labor and majority of the work accounts to harvesting activities. It must be noted that effective ways to automate the grasping of yield produce has been introduced in recent years [22] and one of such effective cutting edge robotic technology is exploited in this research work. This is a modified variant of the rubber arm robot (Stoelen et al., 2016) for pruning and grasping different varieties cauliflower.

These were clear 3D printers, artificial intelligence and early broccoli separation rules. This differs with great accuracy. In previous work, they found that Asus Xtion was not enough and rated Kinect 2, a state of the art with low RGB-D sensors, depending on the innovation during the flight. The sensor is mounted in a housing that is intended for a square sensor element. LEDs are used to compensate for shadows from the sensor. The acquisition of data is done during the day and the evening. Three units of latest RGB-D cameras are used in parallel to facilitate the harvest due to the complexity involved in cauliflowers pruning (with large leaves and strong holding roots) [3].

Harvesting offers the technology to combine huge data packages for the significant distribution of landscapes in order to overcome all barriers between the best visual and computer-based view in the field of mechanical self-control. A data acquisition was set up, which enabled the schematic representation and visualization of the processing computer device. The developed software application is configured in the computer device and used for processing the images acquired in six different perspective.

The virtual separation is carried for all types of data records and fake data records are created, for example experimental images are saved meaningfully and subjectively. It must be noted that fact that there was inconsistency in the number of units for categories and shadows in the acquired data set [4].

Robots are transforming with enhanced capability to be able to carry out tasks that requires human level strength and intelligence. These robots are both in humanoid and non-humanoid forms encompasses. It is already known that human hands are ready for rapid development and high accuracy, but it is prone to internal damage to tissues, ligaments, and muscles due to repetitive intense tasks. The hands of robots are usually softer with good grip profiles improvising the effectiveness whilst deployed in real life scenarios. The operational safety of robots has been one of the major concerns and the chosen robot also offers safety when used around people, whilst not compromising on the speed and overall behaviors.

Semi Static stacking on the elbow. The arm was fastened with screws and the forearm was hammered, separating different focal points to combine the weight of 70 mm to 200 mm from the wrist bar and 10 mm between them. It was connected to range of weights with specific configurations. Several torque states (AX-12A) were used to show a unique connection method. This process was repeated several times with different loads and characteristic separation.

As shown in the figure below, the size can be altered depending on the external torque. The rubber armrest is considered to be extremely sensible and exploited in various applications including (but not limited to) cognitive science, mechanical management and mechanical Self-control [5].

Upon modification of the robot, configuration of the software and prepping the experimental set up, the robot is tested for grasping. This research also illustrates the exploiting potential of recent advancements in Agri technology. It is also possible to create a mechanical framework that influences the environmental requirements. The Information from regional and landscape architecture are used in two CNNs. The strategy used was 91% for Prisoner Examinations based on visual data.

The End effector system comprises of camera, tires, belt drive and delicate handle steamed salads are cut with high yield to keep a strategic distance from the damage.

In addition, the input control box is used to identify the state of terminals to avoid any cutting injuries. A series of experiment conducted derived that the likelihood that a possibility of 52% split of the salad portion. However, in separate tests, the collection results were not effective and reliable enough due to floor restrictions (hand weight, usable working space of the robot arm, and the field of view of the overhead camera). In some studies, reduction in the count of lettuce leaves was expected due to the limitations in identification offered by the camera.

The normal time curve was 31.7 seconds, and the difference was 32.6 seconds. it is worth limiting due to the weight of the closing effect and the barrier on the shoulders [6].

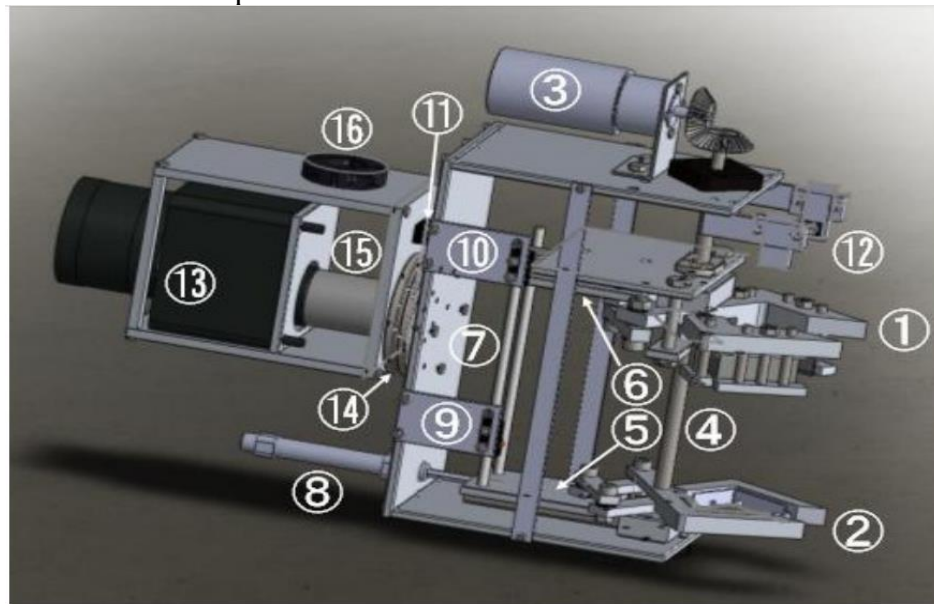
The supplement used in the garden also shows a robot that can collect peppers in this study. It was found to be capable of pruning the pepper stem and placing it in the handle. Frames are used to cut the frame and locate and collect it with the steam camera. Some innovations were used, such as the recognition of innovations, selection innovations and innovations. The robot consisted of two cameras, mounted in a similar housing to facilitate the cutting operation. As the robot was in motion, it was able to locate and cut the stem off the pepper crop. The picture below illustrates the robot model capable of harvesting peppers [7].



Figure 2: tomato Harvesting robot inside greenhouses.

The tomato harvesting robot features task tailored end devices, enabling the collection of individual tomatoes with a finger or a suction cup profile. However, in this test apparatus, there is an end effector that can collect the entire bunch of tomatoes. It is manufactured and tested in a daycare center that uses a certain configuration for a robot arm combination known as SCARA. The framework for the plant preparation called “wire” is known to have been used to plant tomatoes in countries like Japan. Increase the use of large number of tomatoes. The last plant was to collect a whole bunch of tomatoes. The physical and powerful properties of the tomato plant had previously been assessed, this includes the natural width of the product, the required stem spacing, the center of gravity, the stem measurement, the full stem length and the stem length between the primary stem and primary organ. The main barrier is created to collect a group of natural products. In addition, the visual framework of the guideline separator, which enables access to the power supply for the terminal to be treated [8]. The visual framework contains testing equipment and principles that are used to achieve the end result.

The parts from the tomato end effector are labelled accordingly in reference to the illustration below; Upper finger (1), lower finger (2), DC motor (3), ball screw (4), air chamber (8), light sensor (12) key switch (9-11), servo motor (13), roller bearing (14), clamp (15) and neck attachment (16). As shown in the picture below.



No.	Name	No.	Name	No.	Name.	No.	Name
1	Upper Finger	5	Slide Board 1	9	Limit Switch 1	13	Servomotor
2	Lower Finger	6	Slide Board 2	10	Limit Switch 2	14	Roller Bearing
3	DC Motor	7	Slide Shaft	11	Limit Switch 3	15	Coupling Joint
4	Ball Screw	8	Air Cylinder	12	Photo Sensor	16	Set Collar

Figure 3: Labels of tomato harvesting robot end-effector

The SCARA framework has four performance levels and a length of 6 kg. Regular operator movements are often not vertical but guided. The research method for harvesting tomatoes is focused on data acquired from the surface of the tomato. The terminal is required to be moved close to the tomato bar to ensure that the sensor can recognize it. The operator is kept static, so that the air chamber can grip the shaft and the operator initiates the action that moves the end

effector onto the lower contact pedal. Finally, the robot continues with a docile posture to implement the collection plan and it was observed that 20 large tomatoes were harvested during the test [9].

The Self-monitoring robot was found to be used in cucumber plant harvesting in the green houses. The individual components of the hardware and software of the robot is carefully chosen. The key component of the robot consists of a self-driving vehicle, a pressure regulator, a terminal, two computer frames for the identification and 3D display of the crop produce. Finally, a management plot that creates contradicting movements for the manager during the recording. The robot is found to be capable of performing automated selection of cucumber without human assistance. Harvesting of the cucumber is estimated to take 45 seconds in the future the task of improving the rhythm and accuracy of the robot could potentially be assigned to the visual perception system. The harvesting height is usually between 0.8 m and 1.5 m above the ground. Three-dimensional workspace and analysis are used to determine the surface of the finished cucumber. The decision about the geometry of the operator depends on the examination of the robot and the workplace by utilizing a light camera mounted on the terminal [10].

Retroactive mathematics is used to determine whether it is highlighted in the administrator's workspace to grasp the cucumber. The organizer uses the test method to determine a contradicting path from the start of management design to objective planning. It was informed to collect products other than organic products. This also includes the transmission of extended grain measurements, to focus at other aspects including the end of storage and the display of the individual parts of the individual harvesting machines, including an independent vehicle, a control system, a tail light, a frame and an expanded frame management. The presentation of individual components was checked in various studies in the laboratory and children's room [11].

Semantic format is usually employed and depending on the type of command, it is marked as informative or surface-oriented to fine tune the models (for example to operate vector machines or random noises). In is understood that the plant restriction parameters such as size is difficult to visualize form the images.

Eb and Floods focuses on using autonomous robots to improve production efficiency [24][25] and limit repetitions, tedious and portable tasks. The use of independent robot innovations is found to be the driving force in crop production research and development. A simple degree of adjustment is required to fine tune the system to make the system suitable for precise agricultural tests. Armadillo sourced an autopilot robot plan for \$ 50,000, that makes it adaptable and versatile for a variety of agricultural tests. The load capacity of the battleship is 425 kg approx. consisting of two 18 x 18 cm rail units, each with a compatible electric motor device and a 3.5 kW power control. Hiking trails are attached to a removable device that allows the robot to change width and distance. A 48V lithium powered battery is used as power supply lasting for 10 hours approximately. The process has been documented for mechanical upgrades and tested it successfully. The main version of the Armadillo Robot was built up at Hohenheim College in Germany. These were also found to be deployed in cosmetics industry. Therefore, the focus is on improving products and devices for new scientists [12].

The revival of seventeen motorized operators separated by Huang and Milenkovic was discontinued. Every robot has a Euler connection, where three Tomahawks meet at one point. Five triangular conditions were used to solve the inverse kinematic question.

The machine control can be divided into four categories depending on the common organization. In this article, SN (round and hollow curved robot), CS (tubular robot), NR (excellent robot) and CC (particularly suitable for connecting a SCARA type 2 motor arm) are equipped with

a hardware controller, each of them is placed at the top is specified. For example, the animation device of six popular machine tools has been studied for a long time and this test is based on the exploitation of all six connected hardware controllers in the industry [13].

The variety of object-related difficulties of modern hardware drivers result from their geometry, including non-linear conditions. Cinemas, on the other hand, are associated with many different problems: the circumstances in the cinema are related and there can be countless arrangements and specializations. Numerical answers to wrong questions in cinemas are generally not comparable to natural arrangements, and the approach to achieving their goals is based on the construction of the robot. A reverse animation of seventeen mechanical robot controls was found. Such structures have a cardiovascular system because they allow separation and directed film.

The geometric part of this distinction is the intersection of ordinary tomahawks. Contracts that exclude robot inspection reduce registration costs and are found to be less effective. However, information on the wrong installation of cinemas in a microchip is evaluated. Therefore, it is interesting to find a robot structure that offers a structure with closed structures. Writing There are no requirements to check whether the robot structure offers a closed structure or if it requires a closed structure, Since the robot structure is required to have a common six-stage Euler robot controller that constantly forms a closed system [14].

To adjust the robot frame, a laser sensor is connected to the robot actuator capable of determining the distance between the robot and the surface evaluation is used. This forms the matrix in the floor. Since two heartbeats are intended for robot control and an error in the range between two beats, actual changes in the motor power of the robot must be accepted when accessing the relative ranking position. Systems for modern robots. Finally, the effects of the electronization model are examined. This coordination policy concerns a practical, inexpensive and practical system for integrating robots into the research organization, companies and modern institutions.

An efficient cost space was built, where the mechanical factory and the control cabinet were valued. The hypothesis decision regarding this paving technology shows that leveling the foundation is not important, rather the estimated motor energy for robots from this design process seemed important. At this point, the laser check box (LTD500) estimated that the error at the end of the mechanical process was less than 0.3 to 0.4 mm. This special hardware facilitates the implementation of this integration policy and further shortens the time. Since the implementation is found to be simple and convenient, the proposed balancing technology is expected to be fully implemented with backup to thoroughly update your computer [15].

## CHAPTER 3. ROBOT PLATFORM

### *3.1 Picking rig*

The mechanical harvest time for special plants consists of the U-shaped cast aluminum alloy with two automatic arms with variable force, which is adapted to open rubber arms [23]. Each arm consists of three important parts; arm, arm and forearm, in which the final work can be combined with a specific task. The development of various weapons was recognized by an agonistic opponent. Since previous GummiArma types were used to find or collect particularly sensitive and light natural products, the load volume must be increased in order to obtain a special cauliflower collection. This is accomplished by bidirectionally placing the frame with three bars in each of the three sections, for the most demanding joints.

One of its automatic arms is equipped with a tail cutter and the other with a tail knife outlet. The 3 RGB-D cameras are used to reproduce the visual tasks required to control the structure of the inactive arm, so that the arm is fully customized for all teams. This ensures the belt buckle won't work against hidden markings again when it remains open.

### *3.2 Workspace analysis*

Knowledge of the Arm workspace is essential to decide on the locations and orientations for the bricks. Furthermore, workspace analysis will allow the comparison of different arm mounting alternatives. Finally, it will give a qualitative understanding of situations, where Cartesian space is doomed to failure. The Robotic Toolbox provides many functions, such as; kinematics, dynamics, and trajectory generation.  $\alpha$  : positive or negative rotation (in radians) around the X-axis of the "current coordinate system"  $a$  : positive distance, along X, between two joint axes specified in machine units (mm or inch) defined in the system's in file  $d$  : positive or negative length along Z (also in machine units).  $\theta$  is the angle to rotate around the Joint Z axis. The Robotic Toolbox provides many functions, such as; kinematics, dynamics, and trajectory generation. The figure below is MatLab simulation of the cutting gummi\_arm robot, where the joint frames are allocated using the standard DH parameter.



Teach	
X:	0.087
Y:	-0.150
Z:	-0.475
R:	0.000
P:	0.000
Y:	-26.620
q1	0
q2	-45
q3	0
q4	0
q5	-20
q6	0
q7	65

X

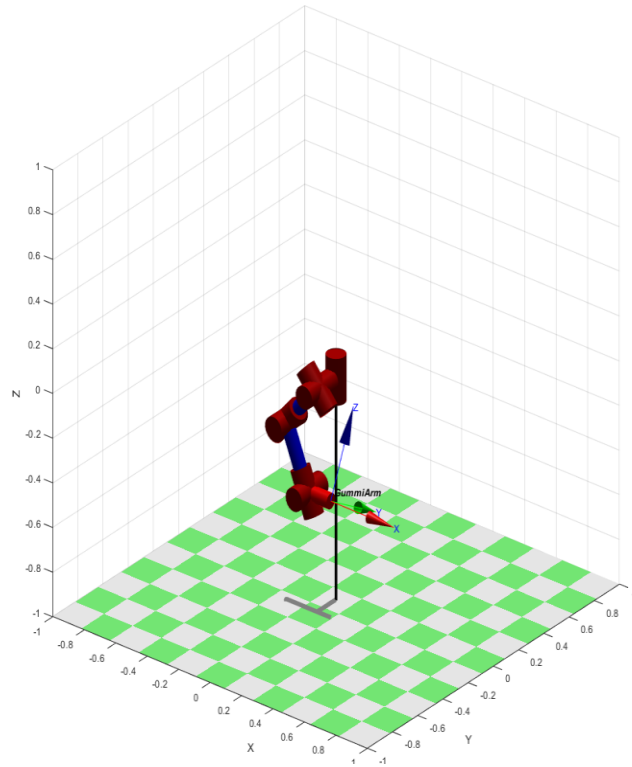


Figure 4 : Denavit–Hartenberg parameters for cauliflower gummi\_arm robot

The robot is equipped with a kinematic frame, which is capable of moving according to the base frame. Forward kinematics is used to move the arm forward. Matrix equations are used to find the best suitable frames. The Dh conventional parameter calculated is shown in the table below.

I	Theta	D	a	Alpha	Offset
1	Q1	0	0	0	0
2	Q2	0.15	0	1.5708	1.5708
3	Q3	0	0	1.5708	1.5708
4	Q4	0.275	0	1.5708	1.5708
5	Q5	0	0	1.5708	1.5708
6	Q6	0.31	0	1.5708	0
7	Q7	0	0	1.5708	1.5708

*Table 1: DH conventional parameter of modified Gummi Arm*

The transformation of the end-effector frame is related to the base frame, which has two transformations, as shown in the figure below.

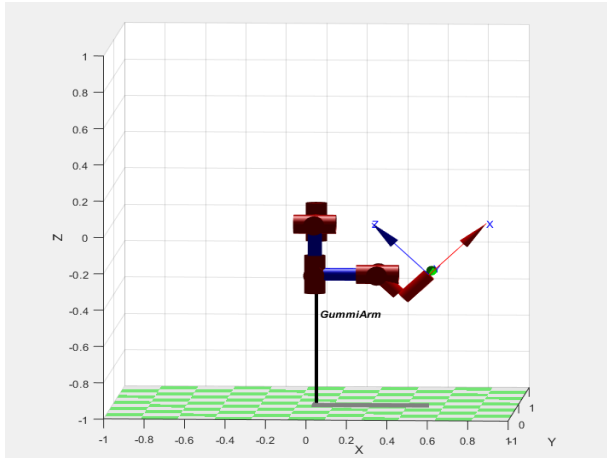


Figure 5 : (DH parameter of gummi-arm with end effector)

Inverse kinematic is a mathematical process that allows to evaluate and find the effective robot joint coordinate, given a homogenous transform representing the pose of the end-effector. The shape of the workspace indicates the robot's experience of Jacobian singularities. The figure below shows the red dots show Gummi Arm endpoint positions that can reach.

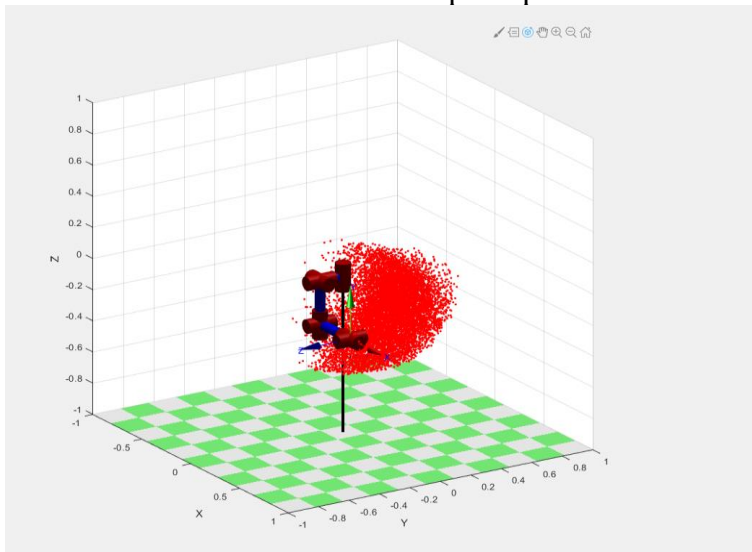


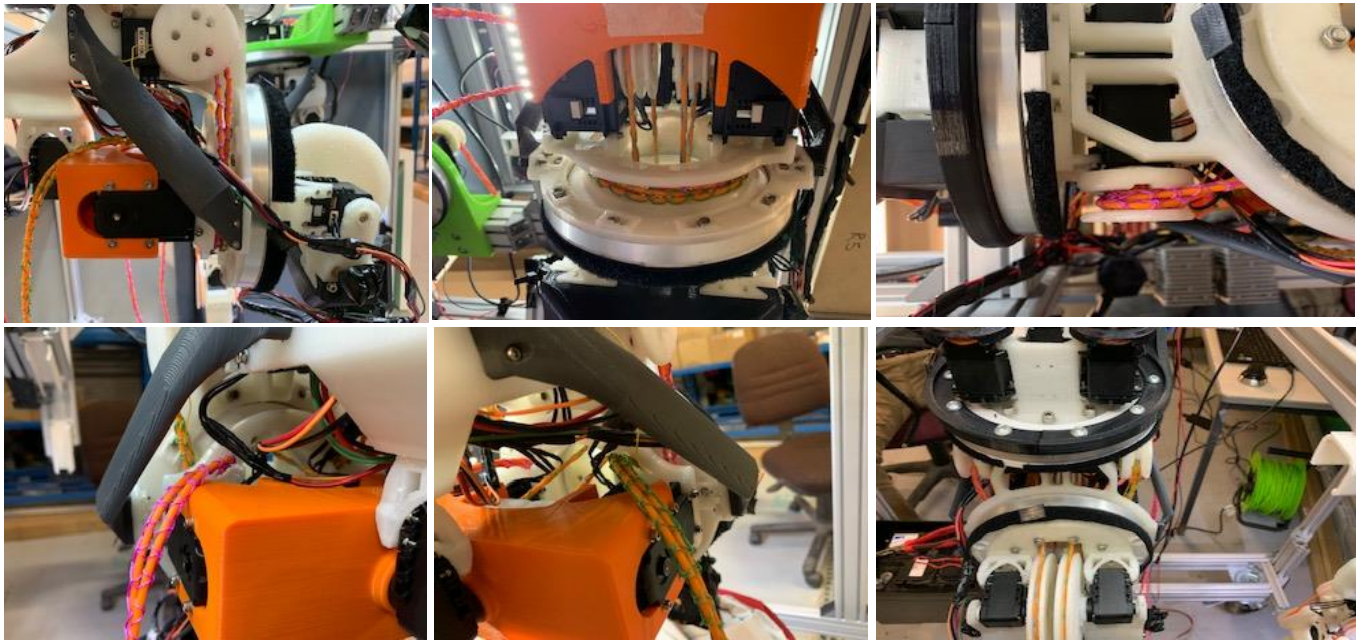
Figure 6 :endpoints of gummi-arm that can reach

### 3.3 Cutting controller

The significance of using the cutting controller is to enable the moving of the system in a straight line, avoiding the oscillating motion and not to reach the singularity. A node developed using python programming language is employed(ROSPY and ACTIONLIB are imported). The

parts of the robotic arm are designed using the designing software fusion 360 and manufactured using 3D printing technology.

To work on the pruning control arm, each part of the robot is required to be set-up correctly. The tendons must be tight enough and mounted in the right direction, even the minor faults are capable of causing major damage to the robot permanently. The servos are tested by Roboplus for each component.



*Figure 7: steps and sides for tiding the tendons to the pulleys*

The ROBOPLUS controls the servos, which regulates the speed and the rotation of the arm with high efficiency and great precision.

### ***3.4 Gummi heavy robot arm***

The GummiArm is a 7+1 DOF robot arm, and is an open-source project. The Gummi Arm robot consists of plastic parts connected to Dynamixel. And the parts of the robotic is connected with tendons to each other. The plastic parts are printed with 3d. The Gummi Arm robot is a soft robot with the addition of variable stiffness — the servos made of PLA-based plastic parts which can be printed with 3D printers. PLA used because it is cheap, and it doesn't take a long period to be published. Another benefit of Gummi Arm robot is the weight; the total mass of the arm is 3kg. The use of fully open-source software and hardware (except servo) allows the control and

adaptation algorithms to construct the soft arm itself in parallel. The parts of the arm can be changed easily with less amount of time. And faster interactive improvement that explore the full design space of hardware and software. Agonist-antagonistic joints for bio-inspired robotic arms have been widely investigated.

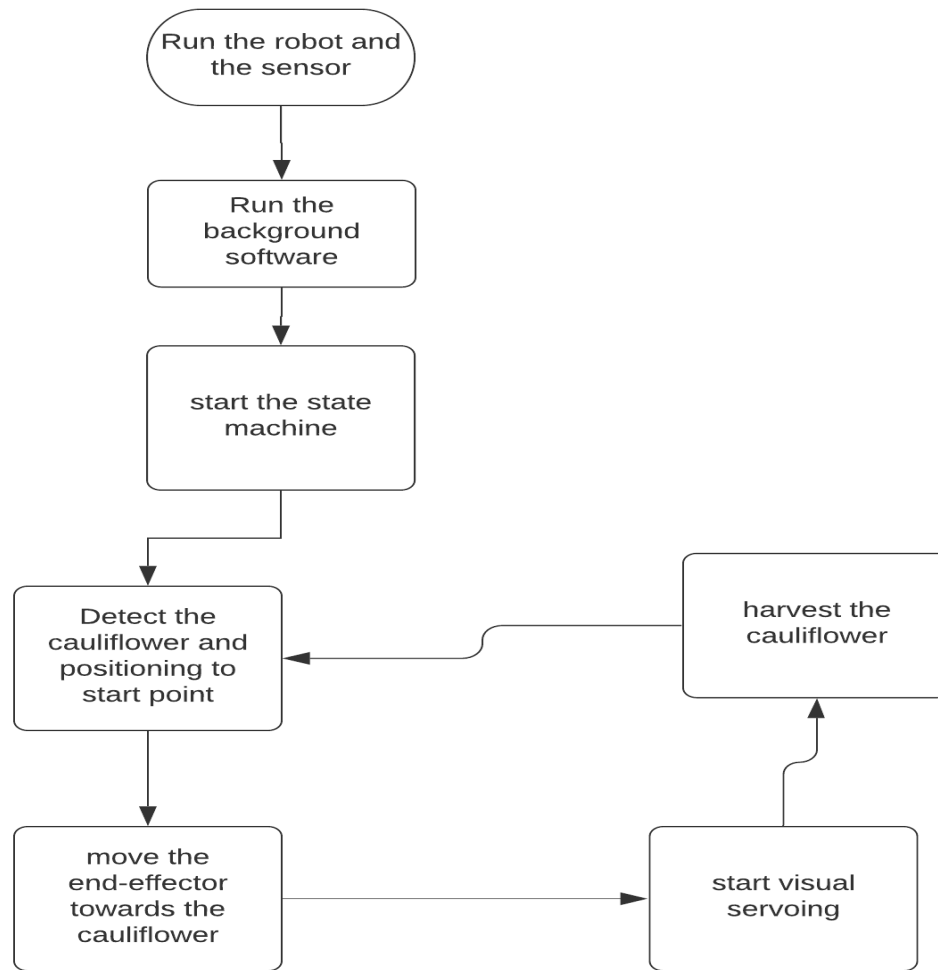
The GummiArm has five electrically actuated antagonist joints. Every antagonist-agonist joint has two uni-directional tendon actuator Dynamixel and one encoder on the joint axis. The tendons have a Filaflex filament of 2,85 mm. For tendons used for Agonist-Antagonistic joints, a quadratic force-length ratio is optimal. It makes it possible to control stifling and equilibrium without sensory feedback independently. For quick point-to-point joint transfers, a two-phase control system is used to monitor the GummiArm. The ranges of each part of the shoulder is different and changing. This set included 270 for brackets (servos of AX-18), 360 for elbow and shoulder turns, and 720 for others (servos of MX-106 T). The co-contraction  $c$  of the actuator servo ranges from 0 to 1 (0 to 100 percent) and correlates  $\pm 90$  scales.

A PID feedback controller was used to provide reasonable performance over the full range of available stages of co-contraction. For each joint, the inversely-modified versions were calibrated. This joint was pushed over the entire joint spectrum and stopped at seven essentially static positions at seven di-percent (0 to 100%) stages.

A linear interpolation may be used to achieve pb values covering the 49 reference points of the convex hull, in other words, the model assumes linearity between the 49 points collected, but if desired, a better sampling scheme might be used. Use of the feature Python `scipy.interpolate.griddata` (a library in Python programming language). For each pair, the entire calibration process takes less than 5 minutes. The correct pb value can be calculated for each joint in less than 1 ms, and an Intel i7 5960X with 3 MHz. An interesting feature of these reverse models is that they can be modified on a quasi-static basis in real-time. This can help adapt the arm output to the work context because, for example, an item of a certain mass still hangs on to a particular task.

### ***3.5 sotware architecture***

In this part, the focus will be on describing the software architecture used in the Gummi Arm robot. In this study, the gummi robot arm used with designed cutting end-effector ROS used for controlling the robot. The robot's software is based on the Robotic Operation System (ROS). ROS is an open-source system made up of libraries and software. that used to speed up the prototyping of robots and share developer experience.



*Figure 8:: State machine of cauliflower harvesting*

The state machine for the system was based on ROS and tuned explicitly to cauliflower harvesting. In general, the state machine is a cycle of different processes, as shown in Figure 2. The cycle starts by (1) locating the arm in stand position, (2) command the arm to move closer to the target, (3) a visual servoing process for precise positioning relative to target steam of cauliflower, (4) cutting cauliflower at wanted position.

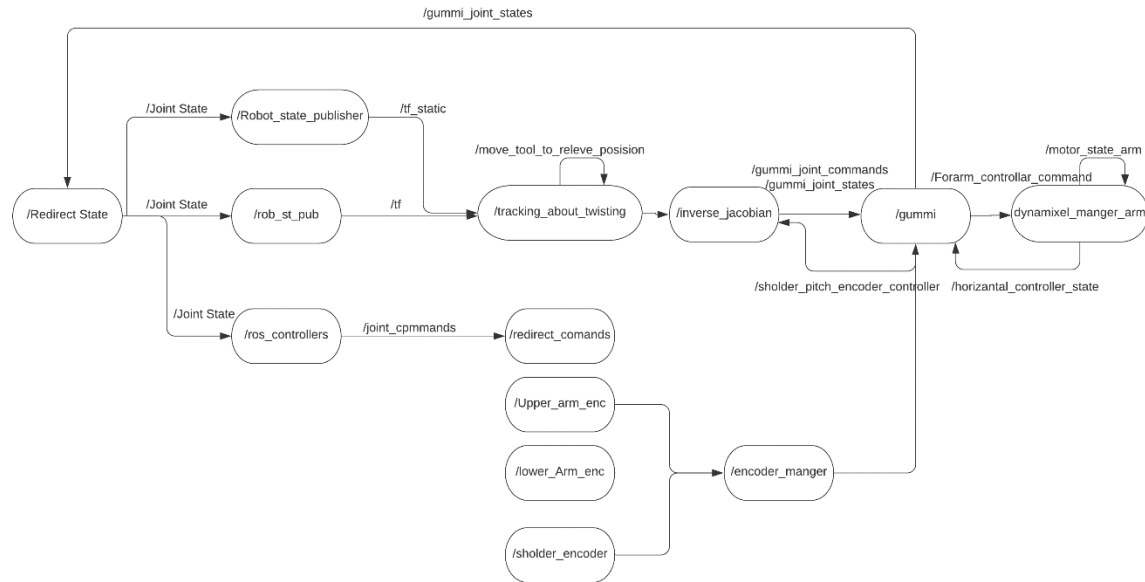


Figure 9: overview of cauliflower cutter software design

Node diagram illustrating the control of a single direct-drive joint (forearm roll) constituting part of the “LowerArm” of the GH2 variant of the GummiArm. The primary nodes shown in this diagram are:

`/gummi`

A feedback controller receives real-time joint position information from encoders through the `/encoder_manager` via subscription to an encoder state topic (e.g., the `/shoulder_pitch_encoder_controller/state` topic in the case of the shoulder pitch joint).

The setpoint (target joint values) set by the node `/talking_about_Twisting_28041_1580401598083`, which provides an end-effector (EE) “Twist” command (essentially a velocity vector for the EE to follow) to the `/inverse_jacobian` node, which creates the necessary joint velocities needed to realize the target EE velocity. These joint target rates are sent to the `/gummi` node via the `/gummi/joint_commands` topic.

`/redirect_states`

Parses the information from the `/gummi/joint_states` topic into a compatible format with the core Ros nodes for RVIZ, `/robot_state_publisher`, and `/rob_st_pub`, which, in turn, passes the transfer functions that characterize the GummiArm kinematic chain via the `/tf` and `/tf_static` topics

## CHAPTER 4. EXPERIMENT 1: FORCE ANALYSIS OF CUTTING

### BEHAVIOUR

#### *4.1 Introduction*

The robotic system is used is to focused on harvesting cauliflower. During the cutting experiment, each cauliflower specimen was mounted into a holder that served to simulate a cauliflower planted in the field. A load-sensing rig was placed against the head of the cauliflower, measuring shear-forces experienced by the cauliflower stem due to the cutting end-effector during the harvesting procedure.



*Figure 10: cutting robot arm & picking robot arm*

#### *4.2 Method*

In the teleoperated with joysticks experiment, a workspace was created using ROS connection connected to a laptop. Python scripts used to subscribe the nodes. Modified gummi-arm robot used with cutting end-effector. The experiment done in a closed area. Four attempts done for teleoperated with joysticks mode. The cauliflower-based on benches-press and attached at down with tools. The steam of cauliflower was on the bench and mounted with a force sensor to calculate the force and time took for the tests. The cauliflower placed 50cm away from the robot arm.

##### 4.2.1 Apparatus



The test set-up consisted of the prototyping rig with two robot arms, only cutting arm used. We have a static testbed with force sensor connected to the computer. The robotic platform for selective harvesting consists of an inverted U extruded aluminum caster wheel mounted frame fitted with two dexterous variable-stiffness robotic arms, heavily modified versions of the open-source GummiArm [21]. The cutter arm made of three main sections, the shoulder, the upper arm, the lower arm like the human arm, and the end-effector is attached to the last part. An agonist-antagonist tendon pulley system used to move the different parts of the arm and connecting the sections. And a bi-directional set-up of the pulley system is implemented for the most demanding joint in all three divisions. 3RGB-D camera used to perform tasks to control the state machine.

#### 4.2.2 Protocol

In this experiment, a cauliflower placed on a static test bench. The robot arm positioned at an initial pose, and then the robot was teleoperated while it was cutting. The robot motors and the cutting motor were powered separately. The power to both the robot and the cutter can be removed via an emergency kill-switch in the case of a malfunction, and the ability to only the cutting motor would remove once the cutting procedure completed or if the cutter jammed in the cauliflower mid-cut.

### ***4.3 Results and discussion***

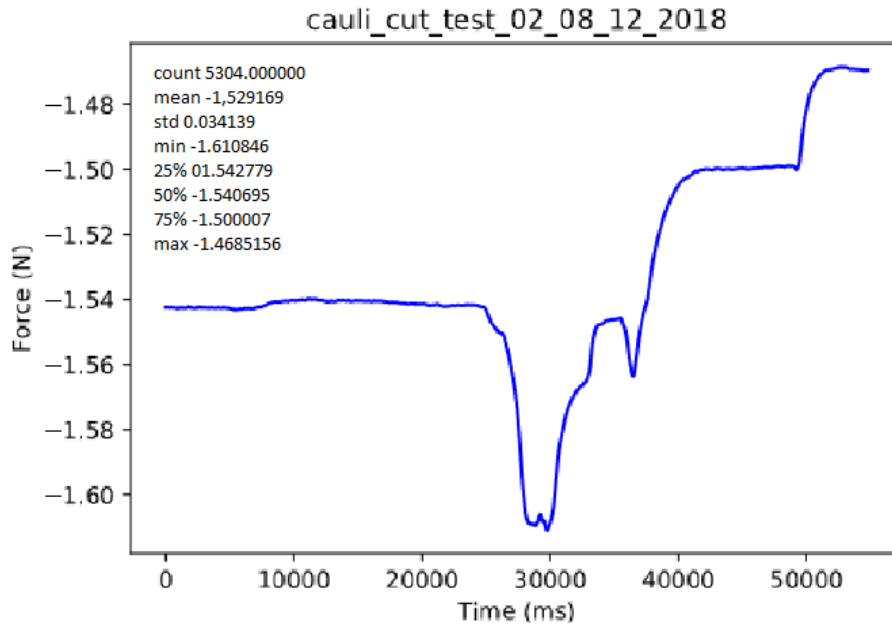
Multiple cutting was conducting using this experimental setup. Each cauliflower was cut through the stem as close to the curd-stem interface as possible—as this was observed during qualitative testing to be the most pliant part of the stem (this was corroborated by how farmers manually harvest cauliflowers in-situ using machetes).

Due to a low-fidelity URDF (“Universal Robot Description File”: quantifies relationship between the joints and links composing the kinematic chain of the robotic manipulator-- used for inverse-kinematics) of the hardware-setup. The fact that the acceptable Range-of-motion (ROM) of the tool was very limited due to workspace constraints that were imposed to avoid singularity and overload conditions (which the system appeared to be at constant risk of experiencing during operation), the end-effector had a tendency to pitch downwards during the cutting procedure. The exact cause of this undesirable behavior is unknown and would occur even when no specimen was placed in the cutting path—so was therefore not solely due to deflection while cutting the stem.

Variations between the measure shear force-curves are likely the result of inconsistencies between the stems of the specimens used. For example, nominal stem width and density-gradation were quite variable across specimens. Variations across the locations of the mounted stems, as well as the system control issues, also introduced uncertainty to the force-measurements.

During the harvesting procedure, the arm was made to generate enough correction force in order to maintain the desired tool trajectory.

Four teleoperated with joysticks mode tests carried out to cut the cauliflower. Only the first test failed. In the first attempt of teleoperated with joysticks mode, the force is appearing strangely to down during the experiment, the cutting end effector. Cutting end-effector stuck in the steam of cauliflower, and male functioned as we can see shown in the figure below. The force is acting, but with a negative sign. So that might be the reason for the y-direction of the joint angle. The reason of getting negative force is due to autocalibration in the sensor. Calibration compressive launch



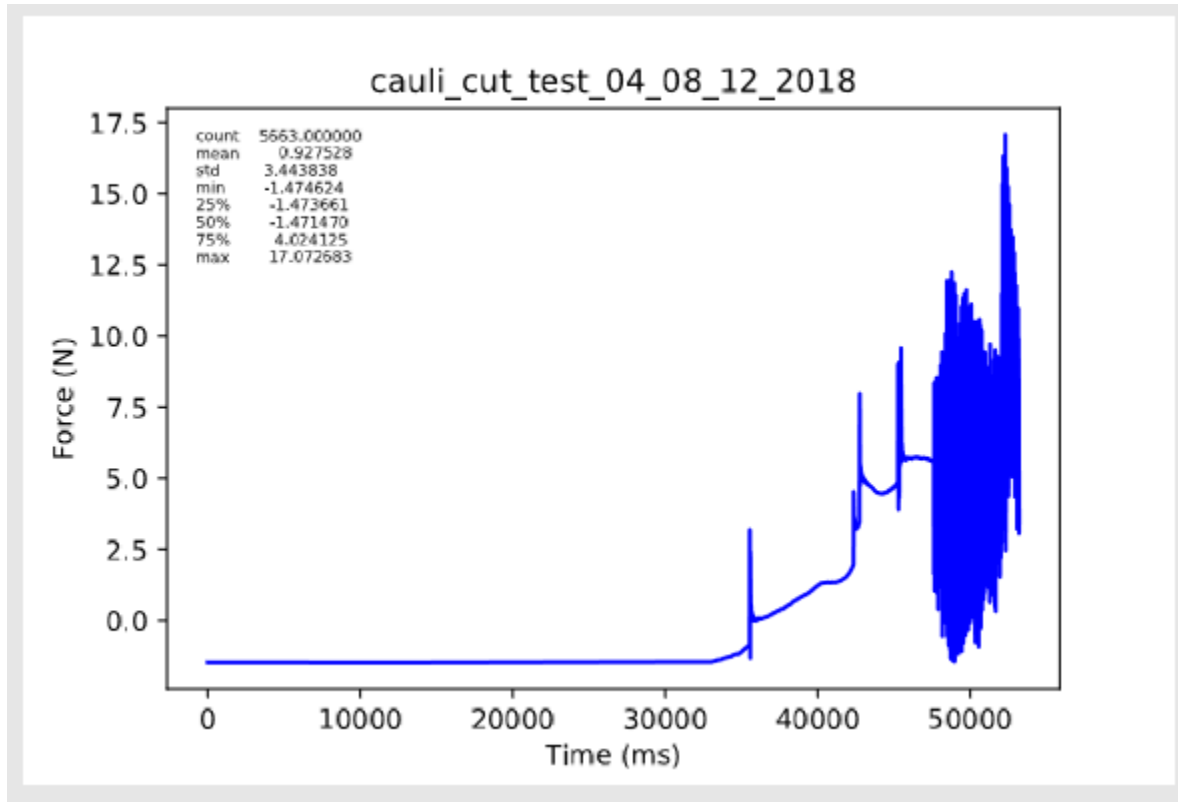
*Figure 11: first attempt teleoperated with joystick*

In the second attempt, the cauliflower cut successful with teleoperated with joysticks. The force is gradually increasing between 100ms to 200ms, and the power was 25N. Then the strength decreased incredibly, which means changing in the direction of axis and the layer of as the layers of cauliflower stem is less dense as much as going down.

*Figure 12 : second attempt of active mode*

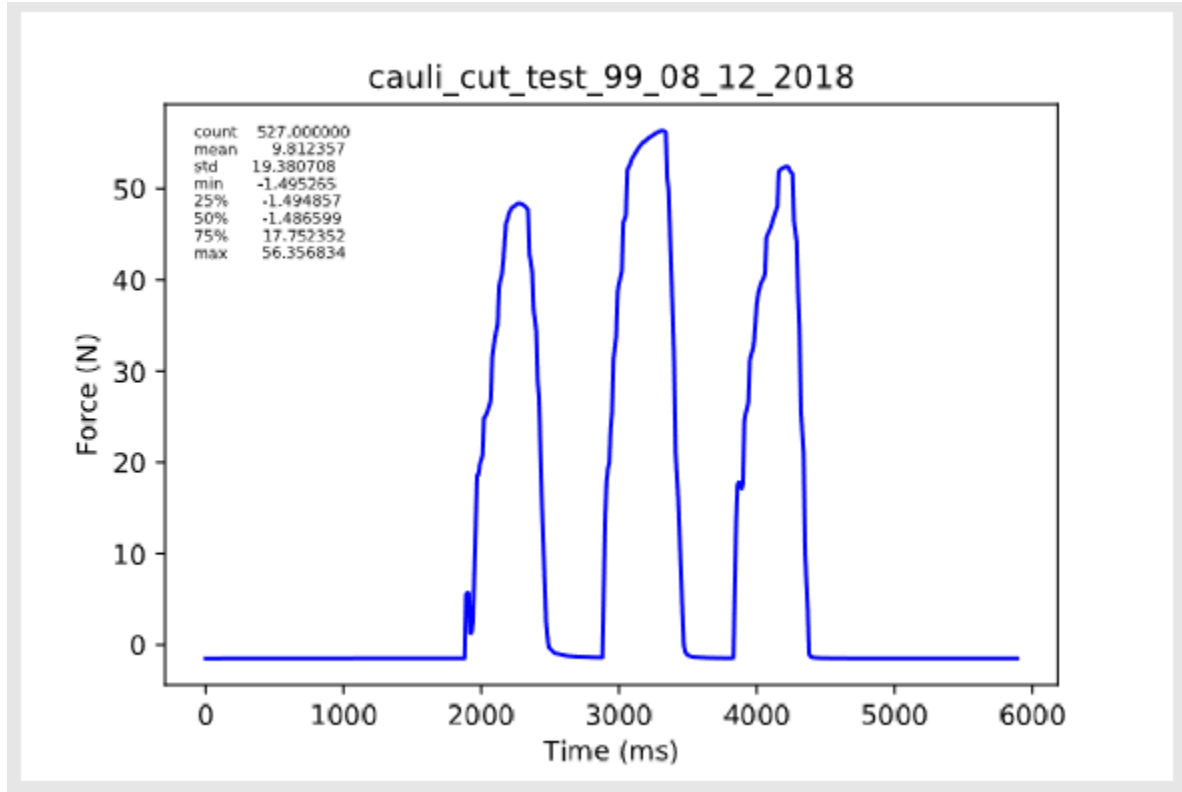
In the third attempt, the cauliflower cut successfully also. The force is 17.5N and with 500ms, which is suitable for a good experiment and the force is acting good position.

At the last attempt, the cutting produces side forces around 510 N on the cauliflower. The cutting



*Figure 13: third attempt of active mode*

took about 15-20 seconds in this test due to the constrained mobility of the arm. Typically < 10 seconds is possible with the current setup.



*Figure14 : force and time for the third attempt of active mode*

## **CHAPTER 5. EXPERIMENT TWO: EXPLOITING PASSIVE COMPLIANCE DURING CUTTING**

### ***5.1 Introduction***

The experimental set-up that used for closed loop mode is the same as teleoperated with joysticks. But the difference is in the end-effector, which have been renew designed.

The teleoperation can be changed freely by the user, loosening, or stiffening the arm joint. arm can be commanded with passive mode, where the equilibrium position of each joint shifted without the exact joint angle control. So, is extremely useful when dealing with physical objects, since the arm instinctively complies with experienced forces.

Passive control will ignore joint deflections until the joint range limits are reached. Passive compliance inherent to the viscoelastic tendons will result in a known linear response provided that co-contraction of the antagonist actuator pairs driving the joint is low enough such that the tendons are in their region of linearity.

## ***5.2 Method***

In this same experiment, methods used as the previous but in closed loop mode. And flex be is used for the experiment three-position are produced clint and server and going back to home. The cutting end-effector renew designed for closed loop mode. During this process, the experienced shear force was logged, the diagnostic information of the robotic setup was captured using a rosbag, and the procedure was video recorded.

## ***5.3 Apparatus***

In this experiment of automated closed loop mode, the same apparatus is used as teleoperated with joysticks mode. Only the change in end-effector renew designed size and power is changed.

## ***5.4 Protocol***

Same protocol is used as the previous experiment no changes in protocol during the closed loop mode.

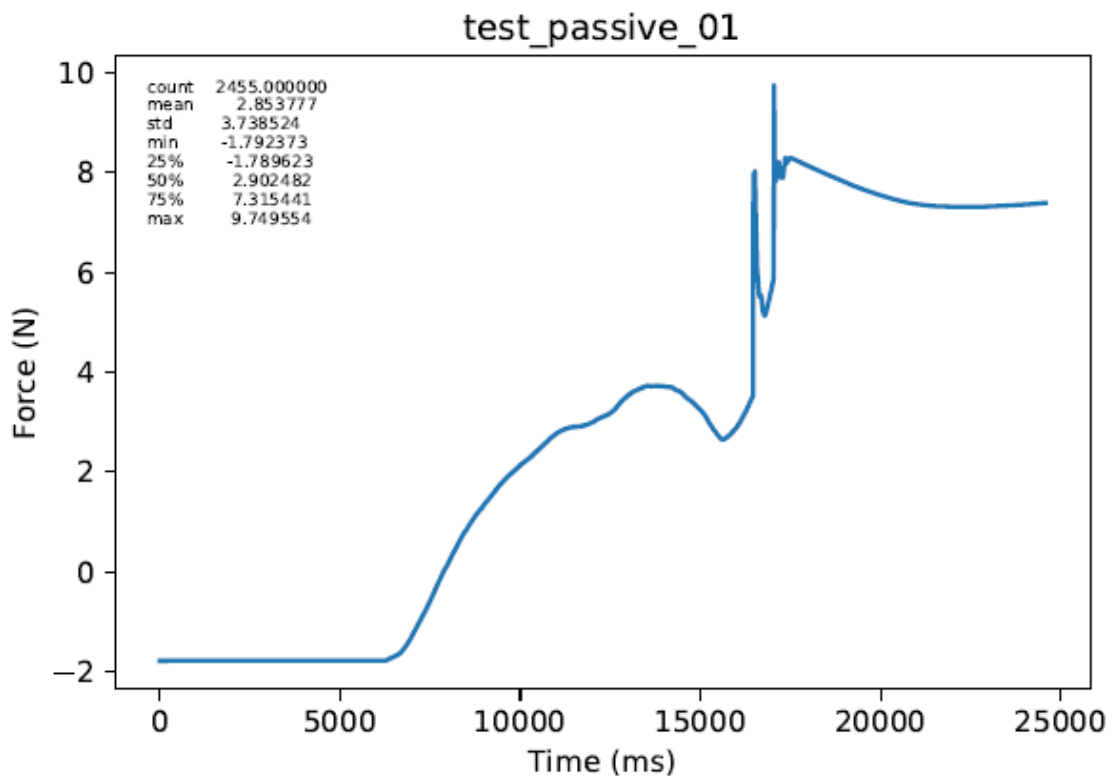
## ***5.5 Results and discussion***

### ***5.5.1 force and time of closed loop cutting robot arm***

Nine closed loop tests were carried out to cut cauliflower. Out of nine tests only three tests were successful and other tests were unsuccessful. Out of the unsuccessful cuts some were high-force

cuts, and some were low force cuts which led to incomplete cutting of the cauliflower. This was because of URDF.

The graphs gathered during nine closed loop tests are as follows:



*Figure 15: force and time for closed loop test one*

As you can see from the graph of closed loop test 1 that the cauliflower stem is not cut completely. From the graph the cutter begins to cut the stem at around 6 secs and there is increase in the force by which it cuts but then force doesn't hold up to the same value. The value of the force starts to decrease because of which the stem of the cauliflower is not cut completely.

Similar kind of observations are evident from the graphs of the closed loop tests 2, 5, 6 and

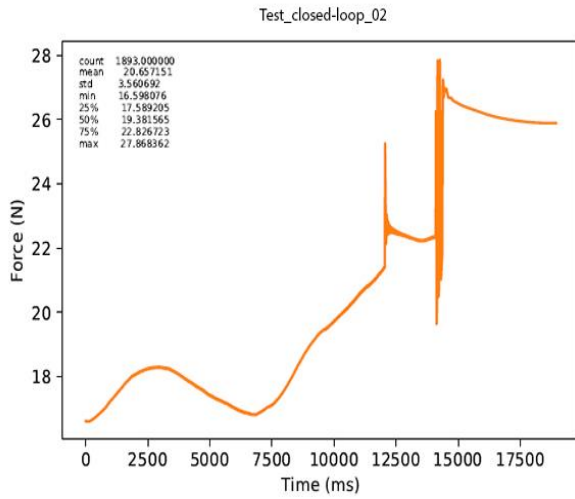


Figure 16: force and time for closed loop test two

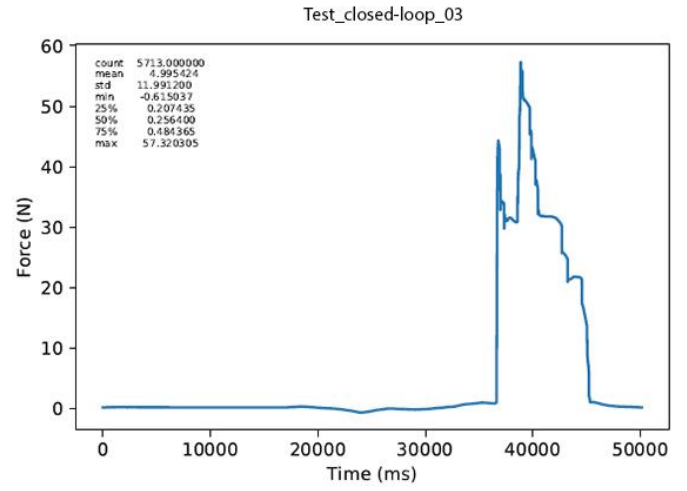


Figure 17: third closed loop test

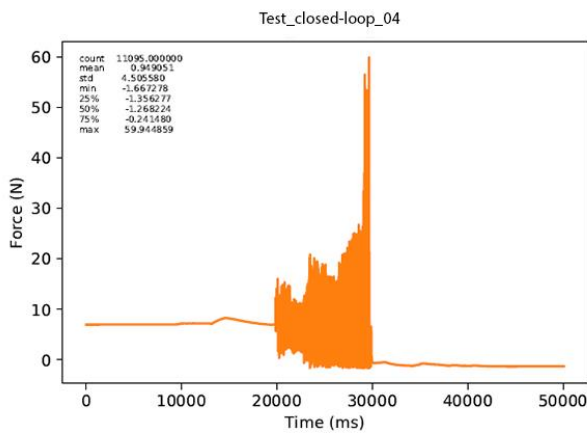


Figure 18: force and time for closed loop test four

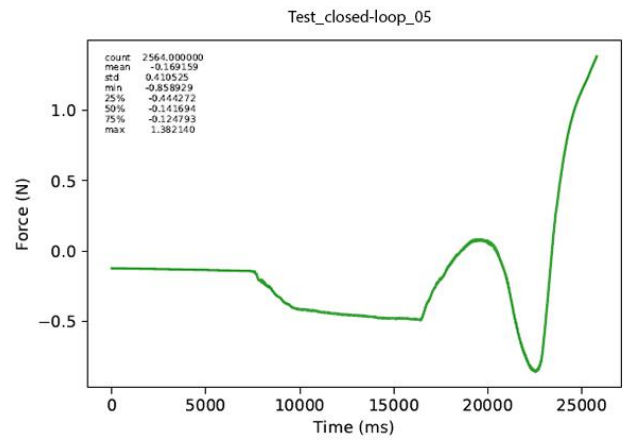


Figure 19: force and time for closed loop test five

F

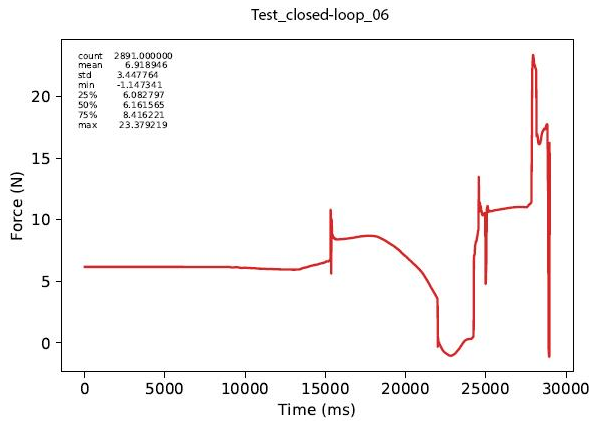


Figure 20:sixth closed loop test

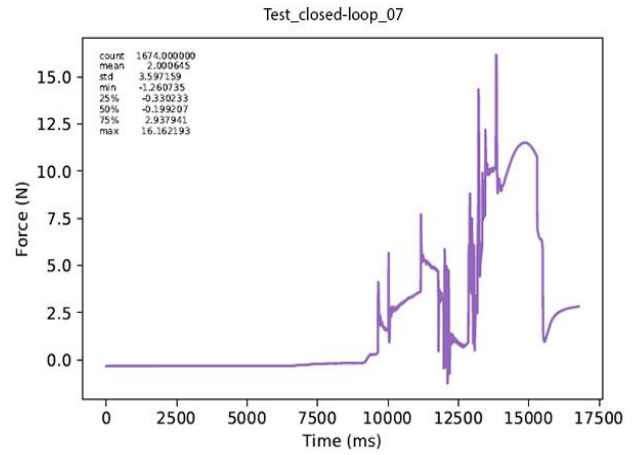


Figure 21:seventh closed loop test

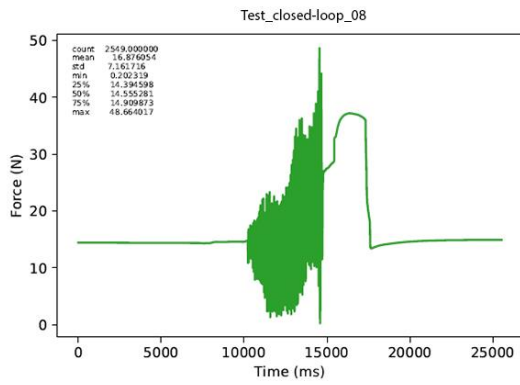


Figure 22: eighth closed loop test

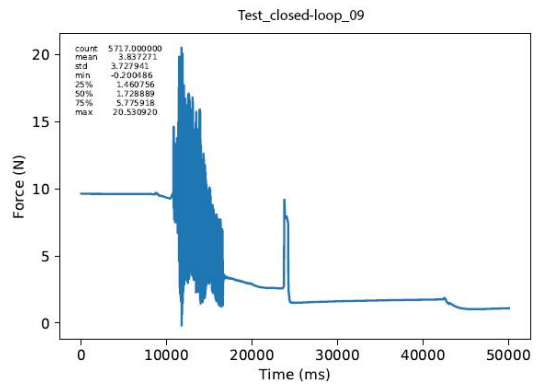


Figure 23: ninth closed loop test



Out of these nine tests, test 3, 4 and 8 were successful and test 3 was found to be the fastest. Other tests failed because of URDF and some other inconsistencies.

Tests 3, 4 and 8 were high force cuts as could be seen from the graph. When the cutter attached to the end-effector of a robotic arm starts cutting the stem of the cauliflower, the cut is steep and sharp i.e. done with high force and hence these tests were successful to get the stem cut completely. Amongst these three tests, 3 was fastest as it took least time to cut the stem of cauliflower. The group plot high-force successful closed loop test is shown in the figure below.

Successful high-force plots

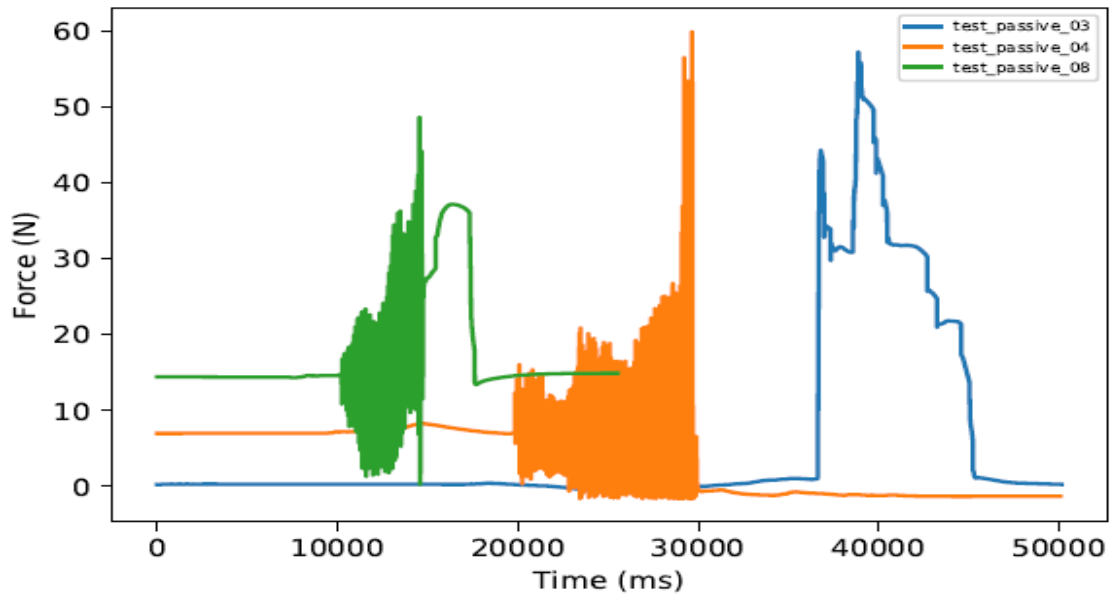
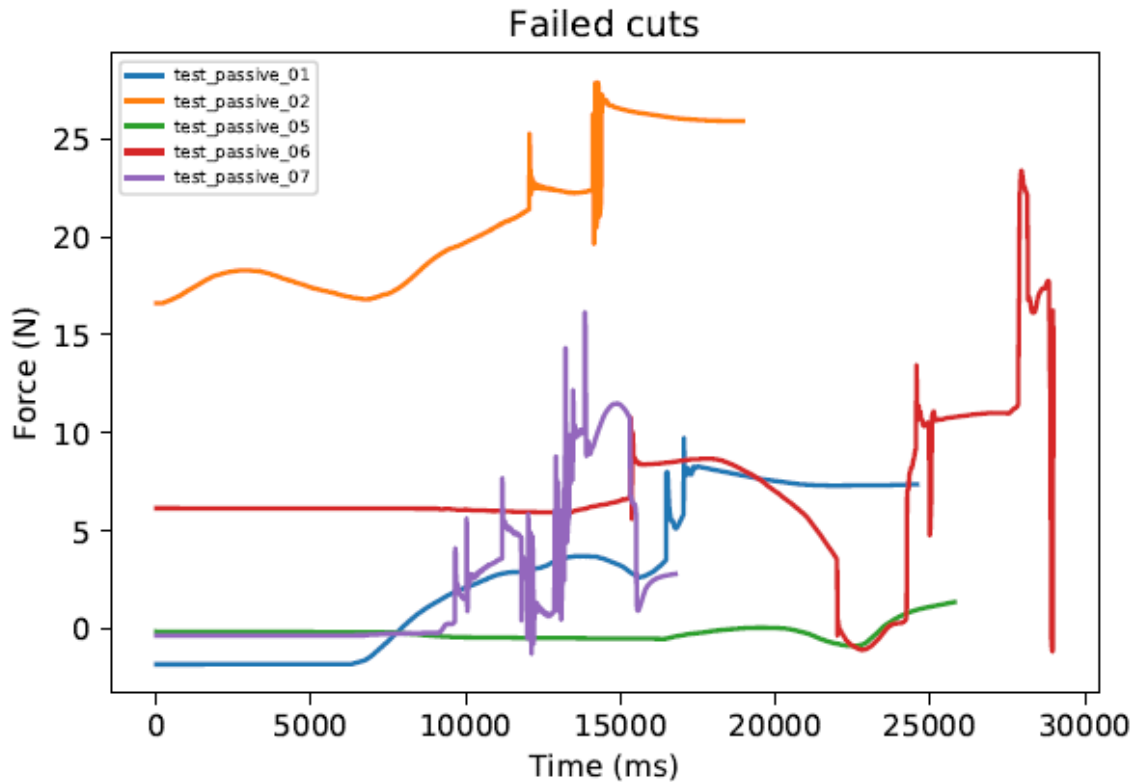


Figure 24: Successful low-force plots

Closed loop test was the only successful low-force plot. The cutter didn't use much force to cut the stem of the cauliflower. And this was one of the other unsuccessful tests.

The Group plot of all the failed tests is shown below:



*Figure 25: failed cut of closed loop tests*

In our experiments we used two types of end-effectors the second one was heavier and a bit bigger than the first one that might be one of the reasons to get a failed cut, another reason was caused by the diameter of the stem of the cauliflower sometimes it was bigger and stronger than a normal cauliflower which will cause a cut failure wire of the cutter, other reasons was the end-effector head was sticking in the cauliflower stem due to URDF or servo weakness. And sometimes malfunction was caused due to overheat in the robot. And it is obvious in the figures that there was force in all of them, but it was going down in X factor.

### 5.5.2 EE\_trajectory pose of closed loop cutting experiment.

As said before, nine attempts made. In this section explaining the poses of end-effector during the cutting process. In the first graph shown that the robot arm is throwing in the side-view is coming down around 20N. This is quite good position for robot because it might be the configuration process. It changes the position in the beginning and can be seen that in overhead-view changes around 10 N, that means the robot going in a good location. Still, the attempt was unsuccessful, as shown before the force was also excellent according to the plots. But as mentioned earlier, the URDF might be the reason.

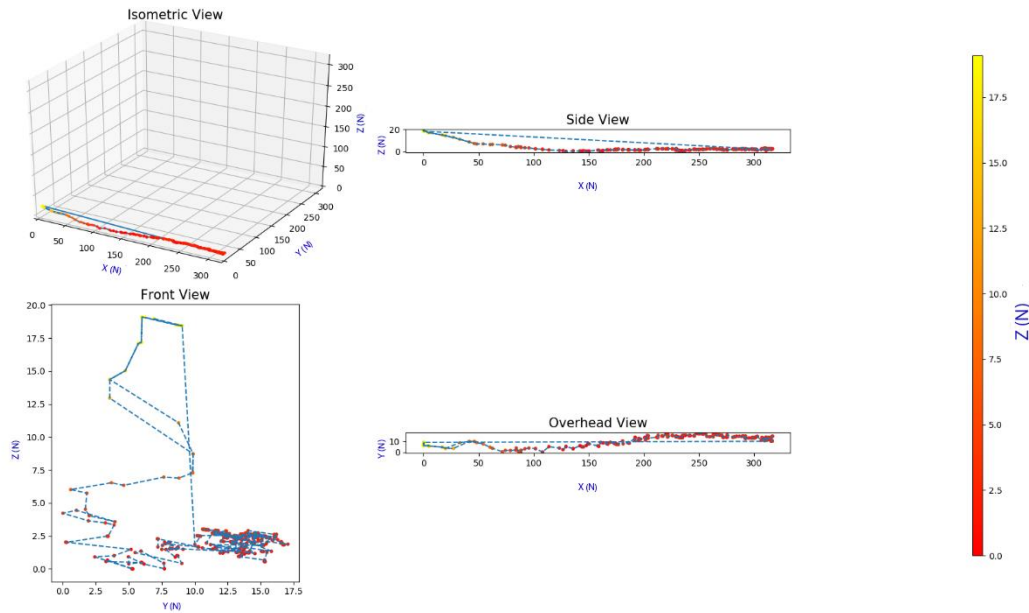


Figure 26 : first attempt ee-trajectory position

In the second attempt, the robot was failure again. And the position is nearly the same as the first one and mentioned that right position. But we can see in this graph at the end going up by 20 N, and then gradually increase to 17N. The robot arm goes typically back to normal position. Malfunctioned and went back to the home position. During the attempt if finished the parameter that given to the robot. And nearly at the end of cauliflower stem, as shown in the figure (27) But it could not cut the stem totally. So as the ten of cauliflower is different that might be reason also.



Figure 27 : cauliflower cutted with robot arm

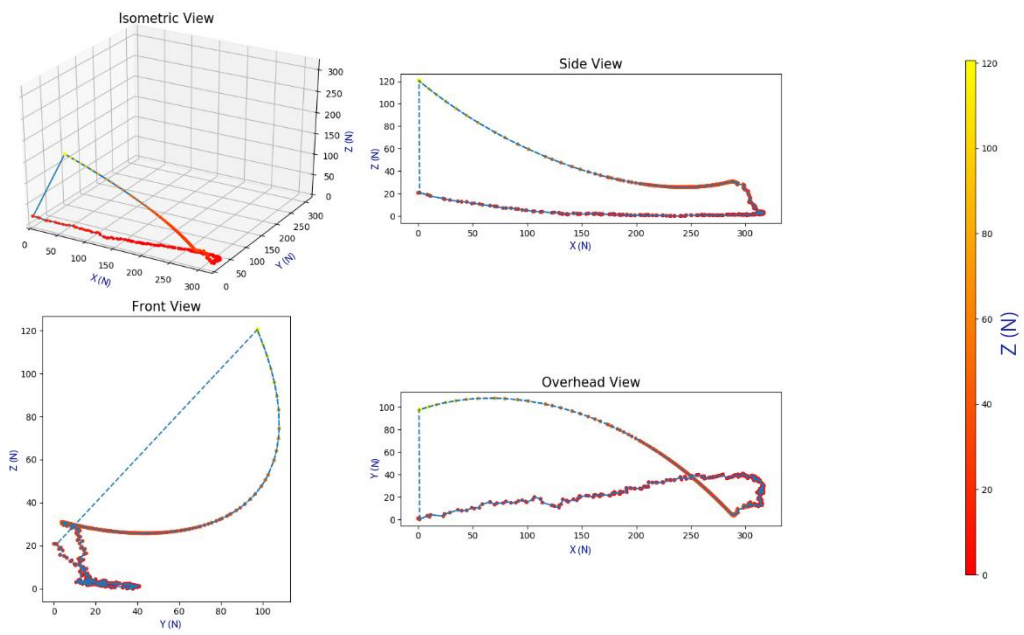


Figure28 : second attempt ee-trajectory position

In the third attempt, no changes at the beginning of the process until robot arm reach 20N, as we can see in overhead-view from figure(29). Because the robot is put far away from cauliflower after that change has happened, which mean the robot made fast movement and just reached the cauliflower and started cutting. And 40N changing in position during the cutting process, and the process was successful.

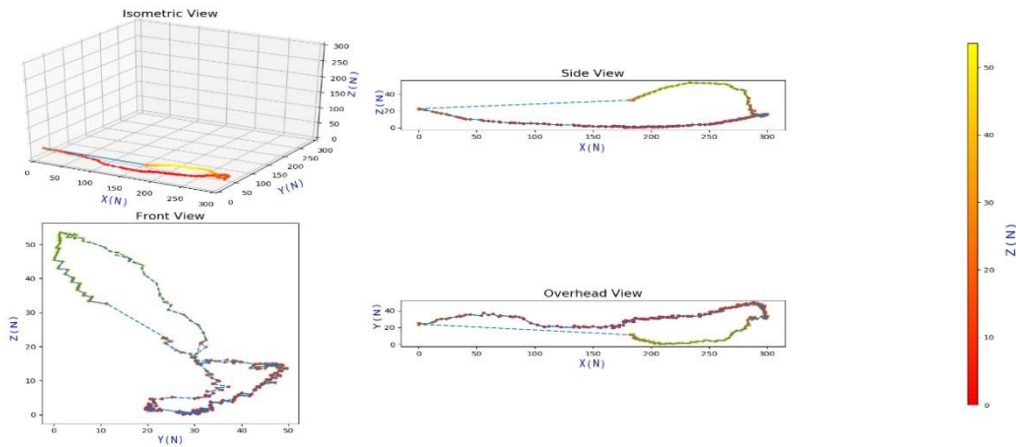


Figure 29 : Third attempt ee-trajectory position



Figure30: cauliflower after successful cutting

In the 4th attempt, the robot arm is moving like an arc shape, which means the end effector is in angle position, and the thrilling is about 60N, as shown in figure (31). The attempt was successful and stuck in the cauliflower steam but then completed cutting. On the other hand, the stem of cauliflower is thinner than the successful one. And the robot does reach to given parameter.

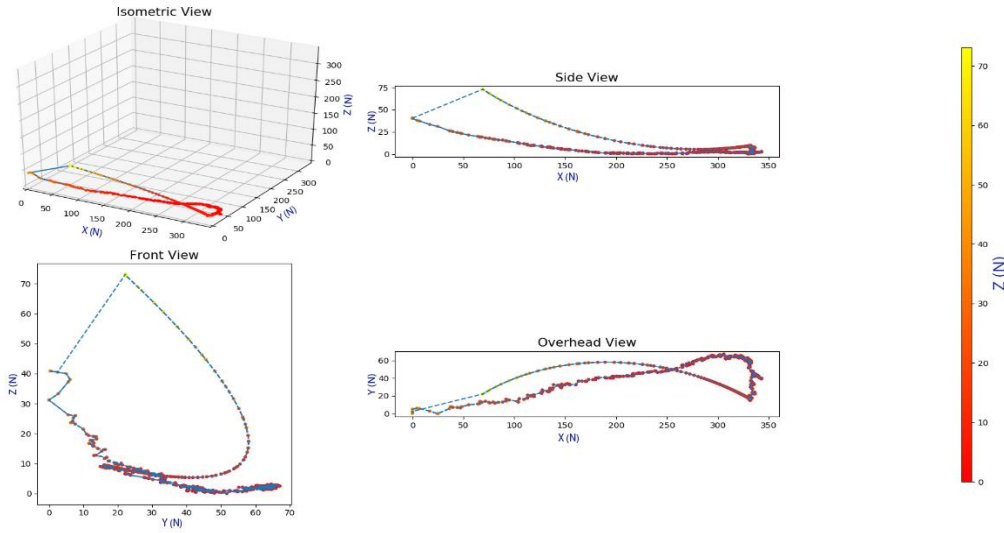


Figure 31: fourth attempt ee-trajectory position



Figure 32: cuilflower with failed cutting

The fifth attempt was unsuccessful, and as we can see in the plot from the side-view is changing about 10N in the z-axis and form an overhead view 40N in the y-axis. Which it is a perfect position and parameter given to the robot just completed in its location.

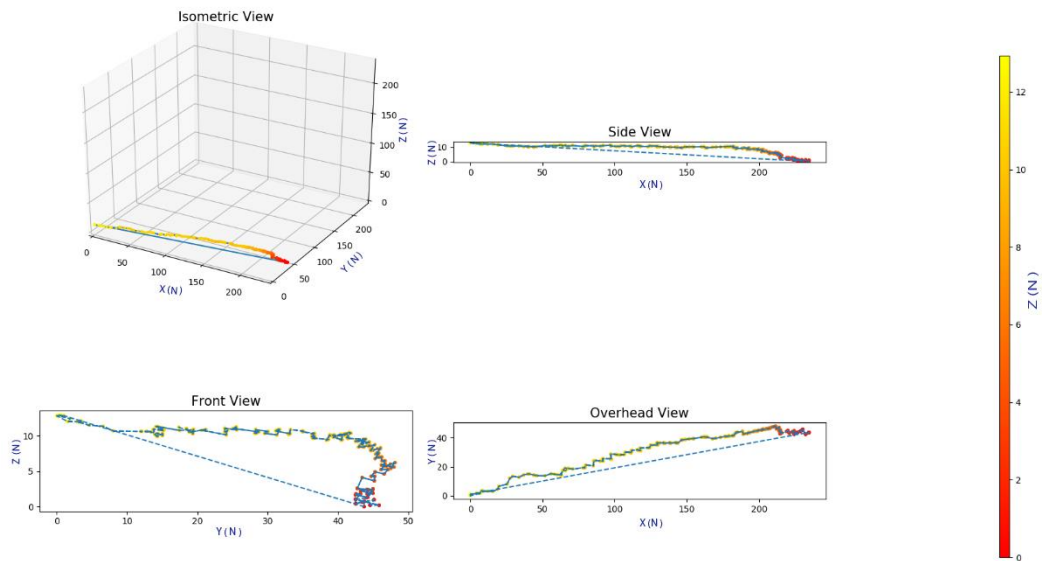


Figure33 : fifth attempt ee-trajectory position



Figure34(a) : top view of cauliflower after successful

figure34(b) : side-view of cauliflower after

successful

Cutting

cutting

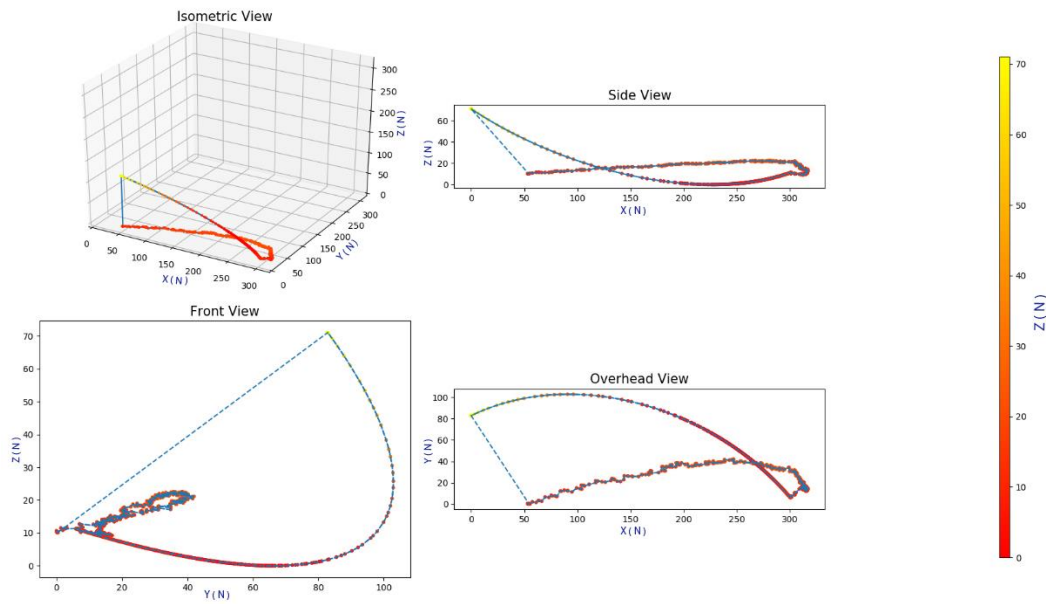


Figure 35: sixth attempt ee-trajectory position



In the sixth attempt, the cutting process was unsuccessful. As the plot(35) illustrates the changing position in the x-axis is 60. The robot arm is coming down with 100N. It is linked with the bunch and made change in the direction the process also in closed loop mode. So that make significant differences in orientation. and may lead to singularity.

At the 7th attempt, the most significant change in x and y position and the effort was unsuccessful, as shown in the figure (36) x-axis is 250N, and the y-axis is if we see the trajectory pose in overhead, we can see that the robot is taking side. So, in this process, the change is definitely can be said that the problem is in URDF. And shows in figure (36) how it come down through the stem comparing to the plot of y-axis.

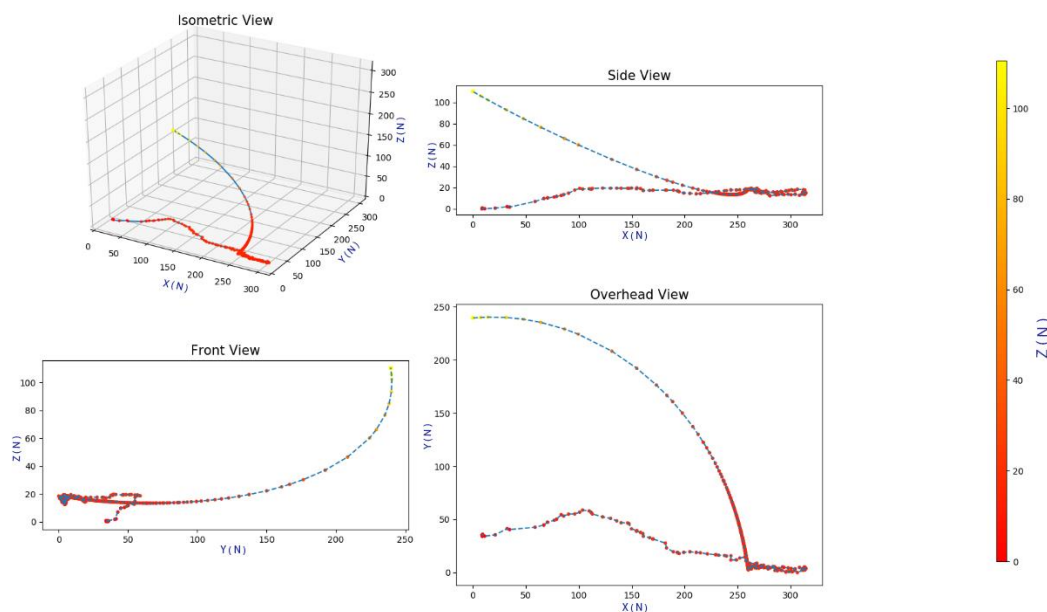


Figure 36 : seventh attempt ee-trajectory position

It can be seen in the figure (37) significant change appears in this plot from x-direction and y-direction, which 80N in y and 250 N in y. And the process is done successfully, and the robot has gone through a given parameter with a short time.

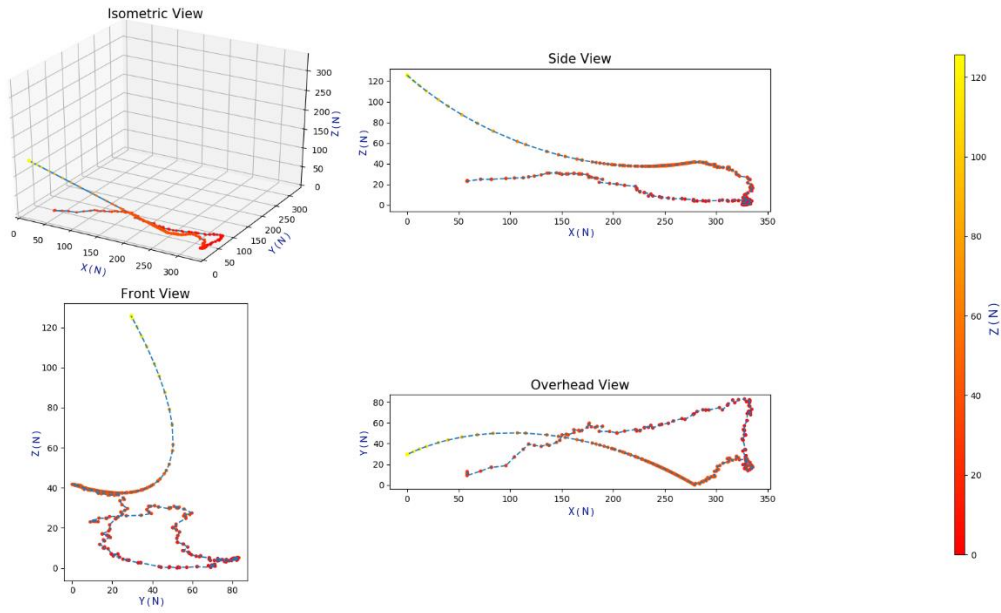


Figure37 : eighth attempt ee-trajectory position

The ninth attempt there is a considerable change in both directions as it can be seen from side view and overhead view and shown in figure (38) the process done unsuccessfully.

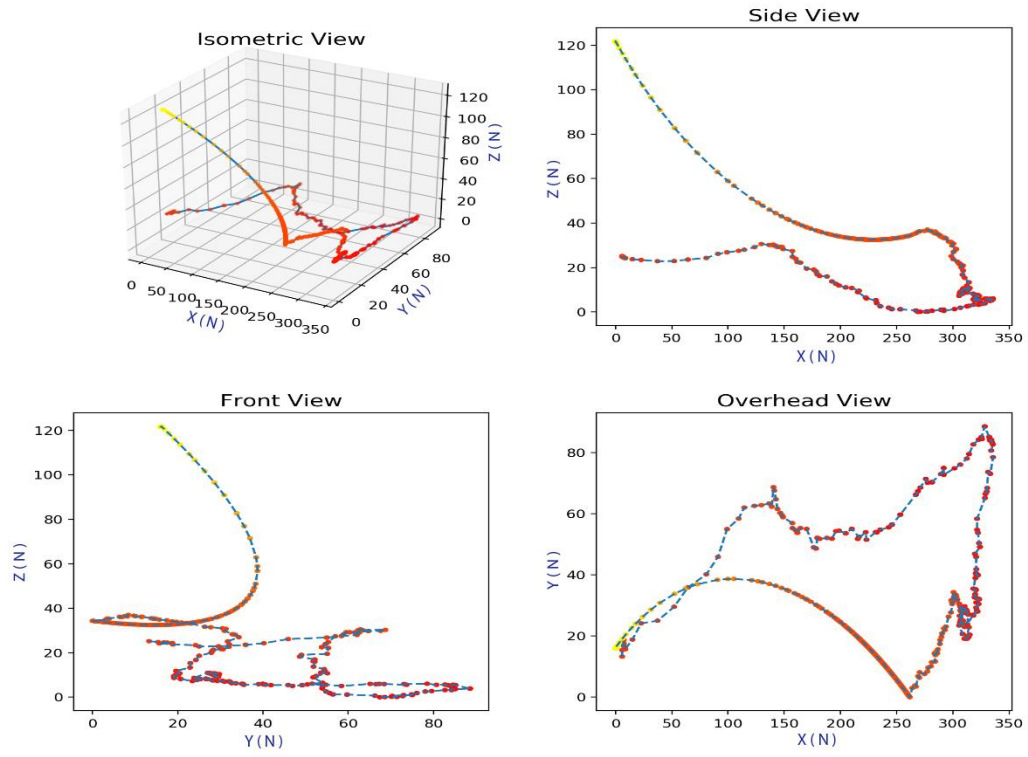


Figure38 : ninth attempt ee-trajectory position

## CHAPTER 6: General discussion

### *6.1 Difference between teleoperated with joysticks mode and closed loop mode*

As shown results, there is a small difference in the teleoperated with joysticks and closed loop mode according to the time. But there is a big difference in the force.

The teleoperated with joysticks performed manually while the closed loop mode can be performed manually and automatically. Test ore spot flaws and fault when specific experiments carried out. But problems and defects are detected by inspection. The software quality is in best manner is enhanced in teleoperated with joysticks testing than closed loop test. The closed loop test checks the software after each iteration while the active testing checks only ones.

Greater co-contraction results in a reduced range of linear responses for an externally applied force. When using the teleoperated with joysticks controller, the system will disregard external forces and attempt to maintain a planned cutting trajectory without complying to the resistance of the cauliflower stem. The closed loop is only negative effort, and the action is a positive effort. The force that acts on the cauliflower will be corrected in the teleoperated with joysticks mode while in the closed loop will not be corrected. The joint limit of the closed loop system will not go more than required. Active vibration control is a technique for reducing unwanted vibration by using some kind of sensor to measure the motion or force or acceleration or other parameter of thing that is vibrating and powered actuator to generate.

### *6.2 Taking over Farm Labour*

Robotics was launched because scientists are unveiling a mechanical model that is ready to perform tasks that only humans can imagine. A team of experts from Cambridge University has built a robot that can move so quickly that it is ready to receive a lettuce, locate the outer layer of the leaves, and gently pull it out [26]. The machine can carry out this series with three tools: a camera for assessing individual heads of lettuce and for recognizing the stem, an arm winding and tearing off a salad, and the second hand with a suction device at the end for removing the leaves.

The moment they collect the lettuce, the lettuce leaves must be removed before the lettuce goes on sale,” said Luca Crimea, one of the researchers, in the announcement . “The leaves are fragile, cut effectively and the condition of the lettuce is rarely guaranteed.” was manufactured by the engineering department laboratory and is currently ready to discard whole sheets in about half a time and in about 27 seconds [26]. Although this new type of robot is not yet used in the field, Scimeca claims to be reforming the way the ranch will be separated and completed later.

For farmers looking for more productive and humble harvesting methods, this can be exciting news. However, it could become a mechanical precursor to the movement of farmers. According to the U.S. Department of Agriculture, 2.6 million people are employed in the U.S. agricultural sector. So far, tests have shown that robot personnel are cheaper than manual labor.

### ***6.3 Efficiency***

Robots can help tons of work monotonously and seriously. Given that certain activities, such as harvesting cauliflower, appear fundamental, it is appropriate that sooner or later an initiation usually takes place. When you do this, there are several factors to consider when hitting the nail on the head [27]. At the end of the day, it turned out to be a real and intellectually demanding exercise that people would get rid of at the last opportunity. This was probably a good incentive to bring together experts from the University of Plymouth, a newly founded robot company that could help them run projects with virtually no effort. The scientists in the project were said to be looking for something suitable for British Brassica breeding and were trying to fold a human hand to meet this requirement. The result is a mechanical arm called a “rubber arm” robot that acts as a person with an articulated arm that can be healed or supplemented upon request depending on the effort and sensitivity of this quality or phase [28].

As from Dr. Martin Stoelen, entrepreneur at GummiArma, wants to fulfil it as an accommodation instrument. With a variety of cameras and sensors in his fingers, he is ready to examine the developing plants and even find out which are useful for harvesting and which are not. “Ultimately, for example, machines make life as simple and straightforward as a pilot,” said Chairs. “Machines can even be” repaired “during the development phase so that the centre’s innovation can be translated into different activities - such as rooting or using insecticides [29].”

It’s also a cool innovation that can get young people to choose a career in agriculture,” he said. And can be further customised to allow more vegetarian choices. At this point, the focus of the group is on improving efficiency. Machines, which reduces the risk of misunderstandings. (Related topics: Agricultural robots control crop growth, provide information, and constantly search.) According to David Simmons, CEO of Riviera Produce, now a partner of the company, this new use of robotics can bring a lot of light into tons of things [30].

The cost of picking up can be up to 40 percent of the cost of making a bra, and talented harvests are becoming increasingly difficult,” he said. “In a serious mall where our customers need a moderate diet, harvest costs are constantly increasing. Mechanical harvesting can increase profitability and control costs. Likewise, assistant robots have not yet peaked with a new innovation [31]. It is quite possible that it will Could replace people and take their jobs away from them.

### ***6.4 Automated broccoli harvester turns to Fanuc***

Fanuc robots are included in a special automatic broccoli collection frame, which could change the UK vegetable industry even with obvious production costs. In the UK, over 75,000 tonnes of broccoli are grown and harvested annually. Business breeders typically rely on a group of seven people who physically harvest grain. Tired work occurs regularly under catastrophic working conditions and can accelerate annoying wounds and other complaints [32]Labour costs are an important cost factor for British farmers, and a change in the country’s living standards will increase manual harvesting costs by 35 percent by 2021, reducing the severity of British farmers and enabling production with minimal effort. In order to promote future research for broccoli growers in the UK, the masters of agricultural research and development at KMS Projects have created a plan to develop a special automatic crop that will reduce the demand for manual crops, thereby reducing crop costs and crop yields can be improved [33].

With automatic shutdown, three Fanuc 6-target M20iB robots are mounted on the motor, drive and tractor. Each robot arm is equipped with a cutting machine and can harvest broccoli heads at regular intervals - twice as fast and manually. Empty joints and bodies of the M20iB robots reduce the weight, but have the protection rating IP67 to ensure a reliable life outdoors and to protect against dirt, earth and water [34]. The latest servo innovations and 6 core areas of development help stimulate fast, unpredictable activities in the area of limited harvesting. For Fanuc robots, there is an indirect visual placement frame that ensures that the broccoli heads that meet the specified size requirements are collected. Due to the visible field of vision, automated devices are not only faster than manual picking, but can also work successfully at night and contribute to the profit [35].

One can also monitor real-time HMI information checks in the tractor housing and external contact services. Although the frame is now made for broccoli crops, it may be adaptable to automate crops from other types of cabbage and products such as cabbage and lettuce both in the UK and before. Smaller chickens in KMS projects include: “Although the UK rural sector is central to our national activities, growers have to incur snowstorms and harvest costs that can harm businesses and start overseas production [36]. We have a very repetitive and concentrated task of physically harvesting vegetables. In the past ten years, we have created what we consider to be an important automation tool for the selection of a customer-specific product.

Fanuc has long been a great participant, providing the basis for testing and maintaining standard boxes and paving the way for our pre-production schedule for a single unit for the 2018 broccoli season. This year we will take further action and be precise. Use data to fine-tune the show, with the ultimate goal of building a series of three-set devices for commercial use in 2019. Simply put, this can help farmers with their development movements and be increasingly useful [37]. “Oliver Selby, Technical Service Manager at Fanuc in the UK, says:” The benefits of modern mechanisation are enormous and it is amazing how KMS projects use Fanuc robots that have an indispensable impact on domestic vegetable production. Broccoli cultures are just an incredible model to use [38]. Over time, more and more applications will be added as the company recognises and receives a mechanical prompt to be serious. You can’t ignore how the UK growers will face significant cost increases in the coming years, but the development can, for example, offset the possible negative effects and help the future to close the company for a long time [39].

## 6.5 Plant Care

Special herdsman in agriculture will open new doors in population production. Carrots are not only roots, but are also increasingly being individualised for ingredients or physical remedies in individual weeds or plants. For the use of fertilisers and ready-to-drink beverages in small quantities and taking into account the latest sensory data, for example with regard to terrible reactions, it can be used to meet the needs of individual plants (the “plant”) [39] This will significantly reduce the source of information and improve the overall basis for the efficiency of horticultural practices. The aim of these efforts was to present the status of the diabetes field in great detail in order to enable physical roots between and within the drug line. Knowing where the seed is planted is a prerequisite for the plants to appear nearby [37].

This information, where individual plants are located, can be used to indicate where the harvest lines are. Accordingly, this can be used as the right tracker to guide or possibly activate tractors. In any case, this policy may be appropriate for managing suppression tasks. High-precision cm-level RTK-GPS, optical metaphors and data registration frames have been restored for conventional sugar beet seed to identify the seeds during sowing [40] The standard error between the seed card and the actual plant card was between 16 mm and 43 mm depending on the vehicle speed and seed distribution. In short, these variables are evaluated, which affect the state of the system. Seed separation has been particularly important in terms of its impact on the ability to wrinkle seeds when the seed separation sensor is passed [41].

## CHAPTER 7: CONCLUSION

This research described a proof-of-concept platform for robotic cauliflower harvesting. The objective to build a system that can harvest cauliflower fully autonomously reached.

Agriculture is an industry where margins are low; cost efficiency and time efficiency are key. To make the presented approach viable, the cycle time would need to be reduced to that comparable to humans. However, using a robotic system would enable certain advantages, such as a more flexible work force and nighttime operation. The techniques and approaches here have been applied to iceberg lettuce; however, the concepts could be applied to other harvesting and robotic agriculture situations. Further work to investigate wider applicability and developing a more universal harvesting system would increase both commercial and research impact.

Two types of end-effectors to detach fruit have been developed and tested. Concerning software, the ROS framework has worked to satisfaction and, due to its modular nature, has simplified the integration of components developed by different project partners.

Four experiments have been carried out in teleoperated with joystick method only one was successful out of the four attempts, in the closed-loop method nine tests have been carried out three were successfully done, and the other six tests were failures due to x or y direction extra cuts.

More attempts are done to close-loop and show that quicker than attempt with the joystick as the results. so if the robot is given a parameter will be faster than human control. The platform can currently perform the task of cutting it at a desired location along the stem. The robot can be used in cauliflower farms, if the cauliflowers are aligned together in a straight line, the labor cost will be less, and it will take less human power because it only needs the robot to be given parameters like the closed-loop and the time will be less as in some of our experiments it took just 6 seconds to cut a cauliflower seed.

In future work, sensors can be added to the end effector to cut the cauliflower in a more efficient way with more force, and the force will be coming from the robot arm itself without anything else supporting it.



## REFERENCES

- [1] Sanders, D., et al. (2011). "Simple expert systems to improve an ultrasonic sensor-system for a tele-operated mobile-robot." *Sensor Review*.
- [2] Klie, S., et al. (2011). "Analysis of the compartmentalized metabolome—a validation of the non-aqueous fractionation technique." *Frontiers in plant science* 2: 55.
- [3] Stoelen, M. F., et al. (2016). Co-exploring actuator antagonism and bio-inspired control in a printable robot arm. *International Conference on Simulation of Adaptive Behavior*, Springer.
- [4] Sun, L., et al. (2018). 3DOF pedestrian trajectory prediction learned from long-term autonomous mobile robot deployment data. *2018 IEEE International Conference on Robotics and Automation (ICRA)*, IEEE.
- [5] Hemming, J., et al. (2014). "A robot for harvesting sweet-pepper in greenhouses."
- [6] Grift, T., et al. (2008). "A review of automation and robotics for the bio-industry." *Journal of Biomechatronics Engineering* 1(1): 37-54.
- [7] Kusumam, K., et al. (2017). "3D-vision based detection, localization, and sizing of broccoli heads in the field." *Journal of Field Robotics* 34(8): 1505-1518.
- [8] Barth, R., et al. (2018). "Data synthesis methods for semantic segmentation in agriculture: A *Capsicum annuum* dataset." *Computers and electronics in agriculture* 144: 284-296.
- [9] Birrell, S., et al. (2019). "A field-tested robotic harvesting system for iceberg lettuce." *Journal of Field Robotics*.
- [martin] Stoelen, M. F., et al. (2016). Co-exploring actuator antagonism and bio-inspired control in a printable robot arm. *International Conference on Simulation of Adaptive Behavior*, Springer.
- [10] Kitamura, S. and K. Oka (2005). Recognition and cutting system of sweet pepper for picking robot in greenhouse horticulture. *IEEE International Conference Mechatronics and Automation*, 2005, IEEE.
- [11] Kondo, N., et al. (2010). "Development of an end-effector for a tomato cluster harvesting robot." *Engineering in Agriculture, Environment and Food* 3(1): 20-24.
- [12] Das, M. T. and L. C. Dülger (2005). "Mathematical modelling, simulation and experimental verification of a scara robot." *Simulation Modelling Practice and Theory* 13(3): 257-271.
- [13] Van Henten, E. J., et al. (2002). "An autonomous robot for harvesting cucumbers in greenhouses." *Autonomous robots* 13(3): 241-258.

- [14] Nielsen, S., et al. (2012). A low cost, modular robotics tool carrier for precision agriculture research. 11th International Conference on Precision Agriculture, International Society of Precision Agriculture.
- [15] KuCuk, S. and Z. Bingul (2004). The inverse kinematics solutions of industrial robot manipulators. Proceedings of the IEEE International Conference on Mechatronics, 2004. ICM'04., IEEE.
- [16] Abderrahim, M., et al. (2004). "Accuracy and calibration issues of industrial manipulators." Industrial robotics: programming, simulation and application: 131-146.
- [17] Johnson, D.A., Naffin, D.J., Puhalla, J.S., Sanchez, J. and Wellington, C.K., 2009. Development and implementation of a team of robotic tractors for autonomous peat moss harvesting. *Journal of Field Robotics*, 26(6-7), pp.549-571.
- [18] Takeda, F., Yang, W.Q., Li, C., Freivalds, A., Sung, K., Xu, R., Hu, B., Williamson, J. and Sargent, S., 2017. Applying new technologies to transform blueberry harvesting. *Agronomy*, 7(2), p.33.
- [19] de Sousa Filho, G.R., Vieira, H.D. and Rodrigues, W.P., 2015. Comparison between manual and semi-mechanical harvest of coffee fruit in mountainous areas. *African Journal of Agricultural Research*, 10(28), pp.2724-2730.
- [20] Galluzzi, L., Vitale, I., Aaronson, S.A., Abrams, J.M., Adam, D., Agostinis, P., Alnemri, E.S., Altucci, L., Amelio, I., Andrews, D.W. and Annicchiarico-Petruzzelli, M., 2018. Molecular mechanisms of cell death: recommendations of the Nomenclature Committee on Cell Death 2018. *Cell Death & Differentiation*, 25(3), pp.486-541.
- [21] Hemming, J., Bac, C.W., van Tuijl, B.A., Barth, R., Bontsema, J., Pekkeriet, E.J. and Van Henten, E., 2014. A robot for harvesting sweet-pepper in greenhouses.
- [22] Grift, T., Zhang, Q., Kondo, N. and Ting, K.C., 2008. A review of automation and robotics for the bio-industry. *Journal of Biomechanics Engineering*, 1(1), pp.37-54.
- [23] Stoelen, M.F., Bonsignorio, F. and Cangelosi, A., 2016, August. Co-exploring actuator antagonism and bio-inspired control in a printable robot arm. In *International Conference on Simulation of Adaptive Behavior* (pp. 244-255). Springer, Cham.
- [24] Pellegrino, R., Viegi, G., Brusasco, V., Crapo, R.O., Burgos, F., Casaburi, R.E.A., Coates, A., Van Der Grinten, C.P.M., Gustafsson, P., Hankinson, J. and Jensen, R., 2005. Interpretative strategies for lung function tests. *European respiratory journal*, 26(5), pp.948-968.
- [25] Jensen, K., Nielsen, S.H., Joergensen, R.N., Boegild, A., Jacobsen, N.J., Joergensen, O.J. and Jaeger-Hansen, C.L., 2012, July. A low cost, modular robotics tool carrier for precision agriculture research. In *Proceedings of the 11th International Conference on Precision Agriculture*.
- [26] Islam, M.T., 2017. Oxidative stress and mitochondrial dysfunction-linked neurodegenerative disorders. *Neurological research*, 39(1), pp.73-82.

- [27] Dai, C., Zhang, H., Arens, E. and Lian, Z., 2017. Machine learning approaches to predict thermal demands using skin temperatures: Steady-state conditions. *Building and Environment*, 114, pp.1-10.
- [27]ALI, M.A., 2017. RESPONSE OF BROCCOLI (*Brassica oleracea* var. *italica* L.) ON NUTRIENTS AND MULCH MATERIALS (Doctoral dissertation, DEPT. OF HORTICULTURE).
- [28] Rybarczyk-Plonska, A., 2017. Health-related compounds in broccoli (*Brassica oleracea* L. var. *italica*) as affected by postharvest temperature, light and UV-B irradiation.
- [29] Harms, J., Ambrosino, F., Angelini, L., Braitto, V., Branchesi, M., Brocato, E., Cappellaro, E., Coccia, E., Coughlin, M., Della Ceca, R. and Della Valle, M., 2021. Lunar Gravitational-wave Antenna. *The Astrophysical Journal*, 910(1), p.1.
- [30] While, A.H., Marvin, S. and Kovacic, M., 2021. Urban robotic experimentation: San Francisco, Tokyo and Dubai. *Urban Studies*, 58(4), pp.769-786.
- [31] Artz, C., Ward Jr, M.A., Miles, M.V., Brennan, P., Alexander, K.M., Lintner, A., Bright, A. and Kahn, S.A., 2020. Intraoperative liposomal bupivacaine for skin graft donor site analgesia: A retrospective cohort study. *Burns*.
- [32] Arens, A.K., Jansen, M., Preckel, F., Schmidt, I. and Brunner, M., 2021. The structure of academic self-concept: A methodological review and empirical illustration of central models. *Review of Educational Research*, 91(1), pp.34-72.
- [33] Kalisz, D.E., Khelladi, I., Castellano, S. and Sorio, R., 2021. The adoption, diffusion & categorical ambiguity trifecta of social robots in e-health—insights from healthcare professionals. *Futures*.
- Arens, P.F.P., 2017. Genetic analysis of heading cabbage traits.
- Conger, B.V., 2018. *Cloning Agricultural Plants Via in Vitro Techniques*: 0. CRC Press.
- [34]Li, H., Liu, Q., Zhang, Q., Qin, E., Jin, C., Wang, Y., Wu, M., Shen, G., Chen, C., Song, W. and Wang, C., 2017. Curd development associated gene (CDAG1) in cauliflower (*Brassica oleracea* L. var. *botrytis*) could result in enlarged organ size and increased biomass. *Plant Science*, 254, pp.82-94.
- [35]Wojciechowska, R., Kalisz, A., Sękara, A., Nosek, M., Cebula, S., Miszalski, Z., Kunicki, E. and Grabowska, A., 2016. Alterations in Chlorophyll a Fluorescence and Pigments
- [36]Turatti, A., 2016. Process Design and Equipment for Fresh-Cut Fruit and Vegetable Industry. In *Fresh-Cut Fruits and Vegetables* (pp. 169-220). CRC Press.
- [37]Maggioni, L., von Bothmer, R., Poulsen, G. and Lipman, E., 2018. Domestication, diversity
- [38]Kalisz, A., Sękara, A., Smoleń, S., Grabowska, A., Gil, J. and Cebula, S., 2018. Mineral composition of cauliflowers with differently coloured curds modified by the chilling of juvenile plants. *Scientia horticultrae*, 232, pp.216-225.

[39]Rybarczyk-Plonska, A., Wold, A.B., Bengtsson, G.B., Borge, G.I.A., Hansen, M.K. and Hagen, S.F., 2016. Flavonols in broccoli (*Brassica oleracea* L. var. *italica*) flower buds as affected by postharvest temperature and radiation treatments. *Postharvest Biology and Technology*, 116, pp.105-114.

[40]van Eggelen, J., 2017. Explaining phenotypical variation by assessing genetic variation in *Brassica oleracea*.

[41]Hodgdon, E.A., Hallett, R.H., Stratton, C.A. and Chen, Y.H., 2019. Diel patterns of emergence and reproductive behaviour in the invasive swede midge (Diptera: Cecidomyiidae). *The Canadian Entomologist*, 151(4), pp.510-520.

(*Brassica oleracea* var. *italica*) (Doctoral dissertation, DEPT. OF AGRICULTURAL BOTANY).

[42]Bontsema, J., Hemming, J. and Pekkeriet, E.J., 2014. CROPS: high tech agricultural robots.