INVESTIGATIONS ON THE ADAPTABILITY OF WIRELESS SENSOR NETWORKS (WSN) BASED TECHNOLOGY FOR HARVESTING CROPS

By

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(2014-18-113)

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TAVANUR - 679 573, MALAPPURAM
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THESIS

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Kelappaji College of Agricultural Engineering and Technology
Tavanur - 679 573, Kerala
2016

DECLARATION

I hereby declare that this thesis entitled **"Investigations on the adaptability of wireless sensor networks (WSN) based technology for harvesting crops"** is a bonafide record of research work done by me during the course of academic programme in the Kerala Agricultural University and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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CERTIFICATE

Certified that this thesis entitled**" Investigations on the adaptability of wireless sensor networks (WSN) based technology for harvesting crops "**is a bonafide record of research work done independently by **Mrs. Ayisha Mangat (2014- 18-113)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship, associate ship to her.

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Chapter I

INTRODUCTION

In a developing country like India, the challenge of meeting production and consumption is really huge. Lack of availability of labors and reluctance of youth to work in muddy conditions causes a considerable decrease in farmer population. This is a major problem confronted by the agricultural sectors of most of the nations. Scientists and agro specialists have found numerous techniques to overcome these issues both theoretically and practically. Research works in the field of mechanization, modernization and advanced method of cultivations are still progressing with an objective to achieve a hi-tech farming.

Polyhouse cultivation, a cultivation practice which provides controlled and favorable environment to crops and protect it from extreme weather condition is one of the technologies adapted for enhancing agricultural production and productivity. Polyhouse structures are now a common practice in developed and developing countries, which ensures continuous supply of products even in off-season. Government policy in promoting hi - tech agriculture, especially protected cultivation for booming state’s agriculture is getting wider acceptance among the farmers of Kerala and a large number of farmers have started cultivation in ployhouses. It is estimated that there are about 1000 polyhouses in the state, in which varieties of fruits, vegetables, medicinal plants, herbs and flowers are grown. Among vegetables, cucumber (*Cucumis sativus L.)*, tomato (*Solanum lycopersicum*) and cow pea (*Vigna unguiculata*) are the mostly cultivated crops in polyhouses.

Harvesting, especially inside polyhouse structures has been identified as one of the critical and resource consuming operation because of several reasons. The common method adopted for harvesting is manual picking of individual fruit, which is highly time consuming operation. The environmental conditions like temperature and humidity create some inconvenience in the work place for the workers and it is very difficult to remain inside the polyhouse for longer durations. Longer working hours in the polyhouses may cause suffocation and hence farmers often need to take rest exiting from polyhouse. Frequent entry or opening and closing of doors of polyhouses enhance the chance of plant contamination. Also, as majority of fruits are located at a higher level and hence mechanical aids like ladders for positioning is required for proper harvesting. These factors make harvesting as one of the most labor intensive and costlier operation and hence emphasize the requirement of an appropriate system for harvesting in polyhouses.

Evaluations of the biometric properties of the crops help in finding out the appropriate harvesting technique to be deployed. Knowledge of physical properties of crops like cucumber plays an important role in the design and optimization of its machinery. This help out to obtain quality products with reduced wastages (Mousavizadeh *et al* ,2010). Evaluation of physical properties of the crop and fruit will aid in designing a harvester suitably. Despite these, it helps in grading, sorting and some post harvest operations.

Latest technology trends focuses on utilizing developments in electronics and wireless sensor networks (WSN) in agriculture, so as to ensure proper interventions for making agriculture attractive and more productive. Research and developments are continuing in the field of protected cultivation to make it autonomous or semi-autonomous with minimal human interventions. The idea of robotic agriculture arouse here. The robots, an autonomous machine must have a sensible behavior in recognized contexts and should have enough intelligence while carrying out a useful task (Tanuja *et al.*, 2015).

Many technologies have been developed in the field of agriculture for making the field smart by using these small smart machines. Due to the development on automation and intelligence of agricultural machinery, agricultural robots have been designed and developed to perform all kinds of agricultural activities like pruning, thinning, spraying and harvesting. Robots in the agricultural fields for harvesting were introduced in the early stage of 1960s. It was firstly used for harvesting tomato fruit. Later on these technologies were widely used for harvesting strawberries, cherry tomatoes, cucumbers, watermelon, eggplant, orange, apple, sweet pepper etc. Though there are some drawbacks for the operations, majority of the robots can perform with an efficiency of 60 -70 %. Introduction of these smart machines helped to minimize the soil compaction caused by larger machines. It also highlighted less human intervention with better output.

Research and development trends in autonomous or semi autonomous harvesting systems are focused on developing high end, sophisticated robotic units, which may not be affordable or economical for small and marginal farmers. Availability of open source technologies and low cost solutions in the field of electronics has been a catalyst for research and development in this arena and opens up an opportunity for developing low cost solutions. Considering technological advancement and the latest trends, this work focuses on the investigation for the adaptability of wireless sensor networks (WSN) in harvesting operations especially in polyhouses. As cucumber (*Cucumis sativus*) and tomato (*Solanum lycopersicum*) are the most commonly cultivated vegetables under protected cultivation, they are selected for the present study. The study was undertaken with following objectives.

1. To study the mechanical and biometric properties of plants and fruits which influence the mechanical harvesting and indicate the maturity of fruit.
2. To design a remotely operated mechanical harvesting system suitable for WSN based technology**.**
3. To evolve the design guidelines for the optimal design and maturity indicators for a WSN based technology for harvesting.

Review of literature

Chapter II

REVIEW OF LITERATURE

A brief review of work done relevant to various aspects of the present investigation is reported here.

2.1 WSN IN AGRICULTURE

Wireless technologies are undergoing fast improvements in the recent years. Types of wireless technologies used include simple methods to complicated types. Wang *et al.,* (2006) categorized the application of WSN in agriculture and food industry into five, such as environmental monitoring, precision agriculture, machine & process control, building & facility automation and traceability.

Bencini *et* al., (2010) conducted studies on wireless sensor networks for on-field agricultural management process. The system was developed and deployed in three pilot sites and in a green house. The system consist of a self organizing mesh WSN endowed with sensors, a GPRS gateway which gathers data and provide it to a remote server and to a web application. This manages the information obtained and helps the user to monitor and interact with the environment.

Application of wireless sensor networks for greenhouse parameters in controlled precision farming were studied by Chaudhary *et al.*, 2011. Because of fluctuating rain, it was very difficult for farmers to monitor and control the distribution of water to the field considering the crop water requirement. Also, there was no ideal irrigation practice available which was suitable for all weather conditions. In such a case, the greenhouse with WSN application becomes more relevant. Here, WSN along with Programmable System on Chip Technology was used to monitor and control various parameters.

According to Merlin *et al.* (2015), WSN was successfully adapted in the field for irrigation. This technique mainly focused on conserving the water source by irrigating the field whenever it is necessary. It was done by fixing sensors that will sense the water content in the field and used super capacitors as storage devices. The study also concentrated on unmanned irrigation, where human presence was neglected.

2.2 BIOMETRIC PROPERTIES OF CROPS AND FRUITS

The study of various mechanical and physical properties of crops is necessary for the proper design of equipments for harvesting and other post harvest operations.

On the basis of a research conducted by Bolotskikh (1988) on 55 varieties of cucumber, the most suitable variety for mechanical cultivation and mechanical harvesting was identified. Accordingly, Kora- a variety form Netherlands was selected based on their physical characteristics. The varieties with short or moderately short stems (≤50 cm and ≤80 cm respectively) with 2-4 branches and few leaves were suitable for mechanical harvesting. Plants should have the ability to tolerate stand densities within a range of 150000/ha and 200000/ha.

A new method for finding the leaf area index of cucumber and tomato plants was experimentally found out by Blanco and Folegatti (2003). Non destructive type of finding leaf area measurements were found useful in growing small plant populations such like pot plants. This study helped to develop a method for finding leaf area index of two crops such as cucumber and tomato. Five plants were chosen as samples which were transplanted after forty days. The width and length of the leaves were measured using a ruler. Length was considered as the distance from the tip of the leaf to the point of intersection of the petiole and lamina. Width was taken as the distance between the widest lamina lobes. Also, plant height and insertion height of petiole from leaf was taken. Using these values and number of leaves, leaf area index was calculated. This study revealed that, based on linear measurements, leaf area estimations are reliable inside the field. The method followed in this study is simple, inexpensive, and precise and using more number of plants in the experiment may help to reduce the deviations.

Ivanona and Vassilev (2003) conducted studies on biometric and physiological characteristics of chrysanthemum plants at different levels of nitrogen fertilization. The crops were cultivated in an unheated greenhouse. They considered various parameters like stem length, number of leaves, flower diameter and dry mass of plant. Dry mass was calculated after drying the plant material at 80^0 C for 48 hours.

Physical properties of date fruit were studied by Jahromi *et al.*,(2007). For proper processing of date fruit, more technologies have to be developed. The development of the technologies needs to know the properties of the fruit. 500 samples were randomly selected for the study. Linear dimensions such as length, width, thickness and projected areas were measured using image processing technique. Mass of the fruit was measured using electronic balance. The result showed that the linear dimensions have an important role in determining the aperture size of the machine, especially in separation of materials. Also , knowing the weight of the fruit helped in grading.

Naderiboldaji *et al.*,(2008) studied some physical properties of sweet cherry fruit for understanding the nature and behavior of the fruit while post harvest operations. Forty numbers of samples were selected from six varieties of cherry fruit. Three linear dimensions were measured for each cherry fruit, such as length, width and thickness. Cross sectional areas in three directions were taken in addition. Dimensional characteristics such as peduncle length, fruit length, fruit width, fruit thickness, geometric mean diameter, fruit mass, fruit volume, sphericity, surface area were determined. Some dimensional characteristic ratios such as length to width, length to thickness and length to mean diameter were found to be meaningful at 1 % probability level.

Jahromi *et al.,* (2008) carried out researches on various engineering properties of date palm trunk that has to be considered while designing a climber machine that will be in direct connection with the trunk and utilizes its support. Trunk specimens with 1 m height and 45 cm in diameter were covered with nylon and the experiment was done from laboratory. Moisture content and trunk density were taken into considerations, because wood strength will reduce with loss of moisture content. Engineering properties like flexural strength, compressive strength, impact strength and hardness were determined using certain mechanical experiments. The results obtained could be useful in developing a palm climbing machine, like maximum weight and maximum force which the tree can hold while climbing.

Post harvest physical and mechanical properties of apricot fruits, pits and kernels cultivated in Iran were studied by Ahmadi *et al.*,(2009). One hundred samples were selected and their geometrical properties like length, width, thickness, geometric mean diameter, surface area, sphericity were determined. Gravimetrical properties like mass, volume, true density, bulk density were also determined. In addition, mechanical properties like rupture force, coefficient of static friction on various surfaces were also determined. Geometrical dimensions of the apricot fruit, pits and kernels were measured using coulisse and the mass was taken with a digital balance. It was found that, the physical and mechanical properties of apricot fruit, pits and kernels are very important design parameters for designing and fabricating the machines.

Mousavizadehl *et al.*,(2010) evaluated some physical properties of cucumber which was considered to be necessary for processing operations. Three varieties of cucumbers namely Green Gold, Dharwad, and Super Dominus were selected and 50 samples from each variety were chosen. Physical properties like height, length, weight, diameter, skin thickness, colour, length to diameter ratio were measured. Linear dimensions like length, diameter and height were measured using digital micrometer. Length and diameter were considered as largest and smallest dimensions respectively. It was found that, all these physical properties play an important role in designing a related equipment and helpful in finding the optimum harvesting conditions.

Jahromi *et al.,* (2012) studied the influence of different rates of garden compost on growth and stand establishment of tomato and cucumber inside green house condition. Different rates of garden compost treatments and peat treatments were done as 0, 10, 20, 40, 60 and 100 % by volume. Biometric indices like leaf number, plant height, shoot fresh weight, shoot dry weight and root volume of cucumber and tomato seedlings were assessed in these substrates.

According to Jouki and Khazaei (2012), physical and mechanical properties of crops like rice are essential for the design of machineries to harvest, handle, process and store the crop. The evaluation of all the properties of the crops was taken as a function of moisture content. Samples of 50 grains were selected and its linear dimensions such as length, width and thickness were measured using a micrometer. The samples were also tested for bulk density, porosity, sphericity, coefficient of friction and angle of internal friction. The average length, width and thickness of the samples observed were 7.43mm, 2.75mm and 2.53mm respectively.

Physical and chemical characteristics of goldenberry fruit was studied by Yildiz *et al*.,(2014) which was needed for designing equipments for harvesting and certain post harvest operations. Hundred fruits were selected as samples. Linear dimensions such as length and diameter was used to determine the size of the fruit. It was measured using a digital caliper. Mass of the sample was obtained using a digital balance. It was found that length and diameter of goldenberry ranged from

13.92 to 19.87mm, 13.58 to 20.75mm respectively. Geometric mean diameter and fruit mass of goldenberry ranged from 13.66 to 20.14 mm and 2.734 to 3.091 g, respectively About 79 % of the goldenberry fruits have a length in a range of 15.11 to 18.68 mm, and about 85 % diameter was in a range 15.01 to 19.30 mm. Physical properties like sphericity, surface area and projected area were also calculated.

2.2.1 Effect of moisture content on biometric properties

Polat *et al.,* (2007) evaluated some physical and mechanical properties of pistachio nut at a moisture level of 7.1% and 44.5%. Physical and mechanical properties of the nut and its kernel such as length, weight, thickness, sphericity, geometric mean diameter, bulk density, projected area, porosity, fruit mass, terminal velocity and also static coefficient of friction were determined as functions of moisture content. The three linear dimensions such as length, width and thickness were measured using a micrometer. Electronic weighing balance was used to obtain mass and the ratio of weight and volume was calculated using a weight-per-hectolitre tester. An increase in length, width, height and mass of pistachio nut was observed with increase in moisture content.

Studies on some physical and mechanical properties of apricot fruits, pits and kernels were done by Ahmadi *et al.,* (2008). In this study some physical and mechanical properties such as dimensions, sphericity, geometric mean diameter, surface area, bulk density, true density, porosity, volume and mass were determined at 84.19, 17.01 and 17.46% moisture contents for apricot fruits, apricot pits and apricot kernels respectively. Geometrical properties like length, width, thickness, geometric mean diameter, surface area was measured using coulisse and weight was measured using digital balance. The result showed that the fruit had a spherical shape.

Effect of moisture content on some physical properties of apricot kernel was determined by Fathollahzadeh *et al.,* (2008). The study was necessary for the design of various equipments for processing, transportation, sorting and separating. Moisture content varied from 2.86 to 13.03 %. One hundred kernels were selected randomly and its physical properties such as kernel length, width, thickness, geometric mean, diameter, surface area, mass, sphericity, volume, bulk density, porosity etc were chosen. Geometrical dimensions were measured using a micrometer and mass of kernels with digital balance. It was found that with increase in moisture content, all the geometric properties such as length, width, thickness, geometric mean diameter, surface area, sphericity also increased.

Some physical and nutritional values of crab apples were studied by Gezer *et al*. (2012). Physical properties of the fruit like as length, mass, fruit density, sphericity, porosity, bulk density, projected area and hardness of the fruit were measured. All physical properties were determined utilizing a repetition of 20 rounds at 77.83% moisture content. For measuring the size, crab apple was divided into 10 groups which consist of 100 apples. From each group 10 apples were selected and length, diameter and projected area were measured using a micrometer. Projected area was determined using a digital camera and weight of the fruit mass was taken using an electronic weighing balance. The studies showed that, 95 % of fruit is between 23.37 and 33.86 mm in diameter and 97 % of the fruit is between 20.4 and 28mm in length.

2.3 ROBOTIC FIELD OPERATIONS

Robots in the agricultural fields for harvesting were introduced in the early stage of 1960s. It was firstly used for harvesting tomato fruit. Later on these technologies were widely used for harvesting strawberries, cherry tomatoes, cucumbers, watermelon, eggplant, orange, apple, sweet pepper etc. Though there are some drawbacks for the operations, majority of the robots can perform with an efficiency of 60 -70 %.

2.3.1 Robots for Harvesting

Edan (1995) explained a general approach of robotic machine for harvesting fruits and vegetables inside a green house. Accordingly a melon harvester was designed with a Cartesian manipulator, two vision sensors and a gripper. Compared to external conditions, green house provided an easy environment for proper operation and controlling.

Hayashi *et al.,* (2002) developed three types of harvesting robots for harvesting strawberry, egg plant and tomato. They reported that, these robots were able to judge the maturity of the strawberry and had an accuracy of 85 % for identifying the ripened tomato.

2.3.2 Robots for Planting

Cultivation of crops based on robotic platform was used by Dattatraya *et al.,* (2014). The electromechanical system consists of a four wheeled platform steered with DC motor. Depending upon the crop rows and columns, the machine cultivates the farm. Four sensors are used in this machine, namely; IR sensor for sensing any obstacles in the field, block sensor and empty sensor for sensing the seed storage and blockage in the seed drop pipe and the last one - Proximity sensor consists of metal detector for detecting one complete rotation of the wheel. This remotely controlled machine uses solar panel energy for charging the battery.

Shiva Prasad *et al.,* (2014) designed a system for seeding and fertilizing using a microcontroller. The robot and its direction are controlled by a remote. The system has two parts- robot end and control sections. Both the sections possess temperature sensor, ph sensor, humidity sensor, seed and fertilizer dispenser, seed and fertilizer storage, robotic system with motor, power supply and microcontroller. Sensors sense the values and send it to Arduino microcontroller and it trigger the actuator for performing the operation.

2.3.3 Robots for Spraying

The design and development of an autonomous machine for spraying toxic chemicals inside glasshouse were carried out by Sammons *et al.*,(2005). Steel pipes were used as guidance in the field and nylon wheels were used to roll along the pipes. The system consist of a microcontroller to which sensors like bump sensors, infrared sensors, inductive sensors and spraying system are connected. The spray system consists of tank for storing the pesticide, a pump and four valves.

Many of the field activities are now carried out by small smart machines in many countries. By replacing larger machines by autonomous robots, soil compaction is reduced. In case of sprayers and other chemical applicators, very minute sprays are targeted directly to the weed plants. Along with that, row mechanical weed controls also work very efficiently in many of the fields. There are field robots capable of travelling between the crop rows to get the location of crops and weeds using a camera and GPS. In addition to this, robots make it easy to get an automated harvester in the field. (Tony *et al.,* 2005).

2.3.4 Robots for Weed Control

A weed controller mobile robot was operated with Ackerman steering powered by a DC servo motor. The two wheels at the back were operated individually with a DC servomotor. Batteries or fuel- used generator supplied power to the system. Weeds were easily identified since the sugar beet plants were sown at known, definite rows. (Mitsui *et al.*,2008)

Usually working in farm is a tough situation due to restricted space and unbalanced surface. Presence of weeds in the farm makes it more worse. Use of robots for weed control is an advanced technology in agricultural field. A four wheel weed seeking robot was invented for this. A smart hoe, which uses vision system for recognizing weeds, was used for destroying weeds. (Gund and Bope, 2015)

Table 2.1 Development of robots and automated machines in the field of agriculture

Sl No.	Period	Significance
1.	1842	The first grain elevator was used in New York
2.	1845-70	Transition from use of horses to tractors and reduction in labor cost
3.	1850-75	Transition from hand power to mechanization especially for threshing
4.	1854	The self governed wind mill was developed
5.	1892	The first gas tractor was created
6.	1926	The cotton stripper was created for easy harvesting
7.	1945-55	The use of pesticides and herbicides increased
8.	1959	The tomato harvester was evolved
9.	1990s	The use of IT and precision technique became prevalent in agricultural field
10.	1994	Satellite technology began to allow farmers to track and plan their practices
11.	2002	Yamahas industrial autonomous helicopter, the unmanned crop spraying in Japan was done
12.	2011	Introduction of R-gators, the unmanned ground vehicle
13.	2012	Automation in harvest with the help of agricultural robots
14.	2013	Association of unmanned vehicle system international (AUVSI) released the economic impact of unmanned aircraft system used in agricultural precision system

Source :(Tanuja *et al.*, 2015)

2.4 STRUCTURE OF A HARVESTING ROBOT

The structure of an agrobot may vary according to designer and developer. But the common and unavoidable parts consist of:

- Autonomous vehicle / platform
- Recognition system
- Manipulator
- End effectors

2.4.1 Autonomous Vehicle / Platform

Platform here refers to the base support upon which the harvesting set up is mounted. It may comprise of rails, pipes or tracks depending upon the structure of the manipulator. In some robots, autonomous vehicle act as the base support. This moving part or the platform will be driven through the plant rows for proper harvesting operation.

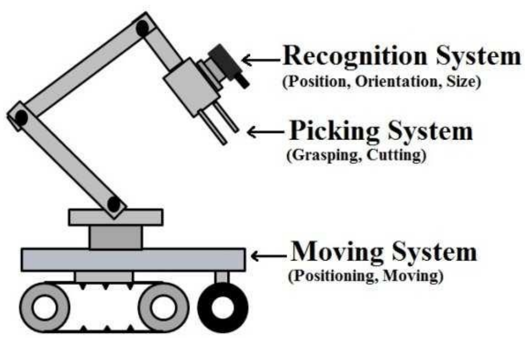


Figure 2.1 Overview of robot (Bachche, 2013)

Mandow *et al.*, (1996) studied an autonomous mobile robot for spraying inside the green house. The robotic platform is octagonal in shape. Since the greenhouse corridors are narrow, the dimension of the robotic platform is constrained to 140cm in length, 80 cm in width. To achieve more stability, the height is limited to only 1 m. An AC generator supplies power to the system which enables continuous operations. It consists of four wheels, out which the front and rear wheels are for steering control. The two central wheels which are connected in parallel are for propulsion.

Another system used for carrying the harvesting system is heating pipes used as rails for guidance and base support. It acts as a moving platform for carrying all other parts. During operation, this platform puts four linearly actuated struts on the ground and thus gains stability. Operation of this machine depends on a life- line, mounted on a reel, which carries 220 V from central power supply. The vehicle is driven by a 24 DC motor and a servo controller and the acceleration is limited to about 0.3 m/s^2. (Van Henten *et al*., 2002)

An apple harvesting robot was designed and controlled by De-An *et al.*, (2011). The mobile platform selected for this type was crawler type. The power supply unit, pneumatic pump, electronic system for data acquisition and control and the manipulator along with end effector for cutting was mounted on the platform. For automatic movement of the vehicle, Global Position System was used. Typical speed of the crawler type mobile platform was 1.5 m/s.

Parisses and Marinis (2011) designed a robotic vehicle with the robotic arm retracted. It consists of two pairs of wheels powered and controlled by two separate DC motors. These motors provide forward motion, reverse motion and a minimum turning radius. This can handle a weight of 200kgs with a maximum speed of 5 kmph.

Automation in sowing the crops like ground nut was done by Zanwar and Kokatte (2012). Planting was done using a DC motor. The bottom platform of the robot consists of a four wheel system. Each wheel is connected to a DC motor, which has 100 rpm and operates on 12Volt power supply. Two sliding bearings are connected at the front wheel which is used for a rotation of $\pm 45^0$. Infra red sensors are connected at the front of the vehicle for sensing any obstacles. Microcontroller is connected at the middle of the panel, which controls and varies the distance between two seeds and also it changes the direction of the robot when the robot reaches at the end of the field.

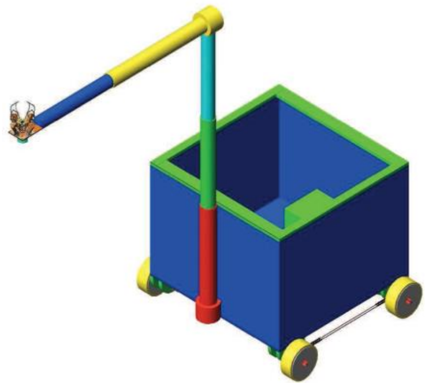


Figure 2.2 Empty vehicle with arm and gripper (Parisses and Marinis, 2011)

Bachche (2013) developed an agricultural robot for harvesting pepper inside green house. The moving system or the autonomous vehicle used for this harvesting had crawling tracks and wheels. This was fully provided with line tracing system that was already laid inside the polyhouse before the harvesting steps begins. This will help the robotic base to move smoothly. The autonomous vehicle was controlled by a control program developed in Mat lab. The main function of this part is to position the manipulator according to the location of the fruit to be harvested.

2.4.2 Recognition System

The main function of recognition system is to identify and locate the orientation and maturity of the fruit to be harvested. Usually one or more number of cameras is used as the recognition part. In green houses, cameras are used along with artificial lightning. The captured images are then transferred to computer grabber interface and then it is processed in the image processing software. An algorithm was then developed for the smooth processing of image. The software can identify the fruits by using light reflection properties and also it provides 3D position of the fruit, stem inclination related to fruit location, stem length and a center reference point. These positional information are fed into the computer and then to the controlling unit.

Generally, camera vision is used for recognizing and locating the desired object. Apart from camera vision, another method used for recognition system is GPS. The advantage of using GPS is that, it will reduce positioning error. A study on Demeter system by Pilarski *et al*., (1999) used GPS system along with cameras. Demeter is a computer controlled speed rowing machine and is capable of planning and harvesting an entire field and also detecting obstacles. Both systems have different types of failures and usage of two systems together will help functioning of one at a time. Mainly GPS is subjected to multi path problems and occluded satellites while camera will not work properly in dim light.

Hayashi *et al.*,(2002) used machine vision system for detecting eggplants using robotic harvesting system. It is based on colour features and morphological characteristics. The original image was captured first, and then low grey level pixels were segmented. Here, colour characteristic of the fruit is used by which the brightness of the fruit was relatively low compared with the background. In order to avoid the chance of detecting stems and leaves in this process, morphological characteristics of the fruit is being used. Hence, vertical long portion was identified as the fruit. This portion was vertically divided using logical operation –AND. To eliminate the short objects, object with a maximum area remained out of the vertically divided portion. AND-the logical operation was used between these two images and final object was obtained. It was fixed that; algorithm can be used under varying light conditions to detect the fruit.

In case of harvesting green coloured cucumber from a green environment, Van Henten *et al.,* (2002) followed the method that highlighted the changes in spectral properties of the leaves and fruits. Leaves show almost same reflection properties at 850nm and 970 nm where as the cucumber showed relatively higher reflection at 850nm than at 970 nm. This made harvesting easier.

For the vision system of apple harvesting robot designed by De-An *et al.*,(2011), image processing technique was used. This helped to recognize and locate the fruit directly, quickly, and accurately. In order to overcome the problems such as low accuracy rate and high time consumption, a real- time automated recognition vision system was used. It consists of a colour CCD camera for capturing the images of apples and also an industrial computer. This enables image processing to recognize and point out the fruit.

2.4.3 Manipulator

Manipulator is a robotic arm comprised of mechanical joints. The number of linkages may vary according to the type of robot chosen. The picking or cutting portion called as end effector is connected at the end of the manipulator.

In a study Hayashi *et al.*,(2002) for harvesting eggplants using robotic system, a fuzzy logic was used for the manipulator guidance. The manipulator used machine vision data to approach the fruit, after the detection of fruit by machine vision unit. Since the machine vision algorithm failed to detect the whole part of the fruit, fuzzy logic was used. Based on the position of the detected fruit in the frame, fuzzy control system determines the forward motion, vertical motion and rotational angle of the manipulator. When the manipulator end reaches the fruit, target area was located at the centre of the frame. With approach of the end effector, the area of the detected fruit gets increased. When the area occupied becomes more than 70%of the total image, the system stops approaching. By the time manipulator end has reached the fruit.

The manipulator is connected to the computer and a controlling program will act as an interface between the user and the robotic arm. This control program controls in two forms: manual and automatic. In manual control mode, operator can input the desired position values and control the manipulator. While in automatic mode, no human presence will interfere in the operation of manipulator and all the harvesting operations will be in automatic condition. This program also has an option of emergency stoppage of manipulator in case of risky or dangerous environment. (Parisses and Marinis, 2011).

Gohil *et al.*, (2013) described a robotic manipulator as a device which is capable of moving in different directions relative to base and which is controlled by haptic technology. Haptic is a new collaboration technology between human and computer, which deals with sensory interaction of humans with computer. Haptic is a Greek word which means pertaining to the sense of touch and here it is used to create a virtual environment. It makes use of the sense of touch by applying forces, vibrations, and motions to the user. In this study, the device fixes a haptic glove over the user's hand. It works like a potentiometer connected on finger and wrist and notes change in resistance with movement of hand. A D.C motor fixed beneath the manipulator actuates its base. The term Degree of freedom is an important term in this field. It is considered as a joint on the arm which can bend or translate or rotate.

Longo and Musato (2013) confirmed that CAD can also be used for controlling the manipulator. Harvesting machine for artichoke was designed and simulated under CAD environment. Firstly, graphical representation of artichoke was prepared. Each artichoke head has a known geometrical position and this property helped in simulations for harvesting. The machine used a dual manipulator configuration, with one manipulator having three DOF and the other with two DOF. When the manipulator reaches the proper position for harvesting with the first cutting tool, system will adjust the second one also.

2.4.4 End Effector

End effector is one of the most crucial parts that are used for picking the fruit from the plant. It performs tasks like gripping the fruit, cutting or detaching the fruit from plant and deposits it for storage or transportation. After receiving the positional information from the recognition system, the movement of the manipulator takes place according to the target location. There are different types of end effectors developed which use different types of cutting mechanism.

The end effector for harvesting eggplant is a vital tool to grab and pick the fruit when the manipulator approaches the fruit. It consists of a fruit grasping mechanism, size evaluating mechanism and peduncle cutting mechanism. Grasping mechanism will softly hold the fruit by using two suction pads and four rubber actuators. Judging mechanism or size evaluating mechanism will select the fruit with optimum size ranging from 125mm to 185mm. It is based on the distance between the photoelectric sensor and guide bars. Photoelectric sensor attached at the bottom of the end effector determines whether it has detected the fruit apex or not. Guide bars detect the fruit base of the fruit to be harvested. Scissors attached on the end effector cut the dispatch the fruit from the parent plant. (Hayashi *et al.*, 2002).

Henten *et al*., (2002) conducted studies in which a camera is mounted on the top of the end effector which is used for imaging the neighborhood of the fruit while approaching the plant. End effector uses a thermal cutting device which gives out a small sparking of light outside to separate the stalks of the fruit. After gripping the fruit, high temperature is applied at the cutting surface using two electrodes carrying high frequency electrical potential. This ensures that the viruses are all killed and also prevents transmission of the same from plant to plant. Since the cutting surface is closed, undesired leakage from the fruit is also prevented, which gives longer shelf life.

Instead of using grippers, a suction cup was used in the end effector. This will reduce damages by securing the fruits inside the fingers. The fruit was first caged inside four fingers instead of firm grasping and then bring it out from the plant foliage without forces acting on the fruit. A vacuum pump controls the suction cup. A camera is mounted at the end of the robotic arm for proper identification of the fruit (Peter *et al.,* 2004).

Feasibility of laser cutting of tomato peduncles for robotic harvesting were studied by Liu *et al.*,(2011). In order to avoid the damages caused to the fruit while detaching the fruit using a robotic harvester, new method of laser cutting was implemented in this field. One hundred tomato peduncles were randomly selected as the samples from the field. Peduncle diameter was measured using a micrometer caliper. The feasibility of cutting with 30W, 980 nm fiber coupled semiconductor laser was tested. The system consists of a laser diode, thermoelectric protection and cooler and a control circuit. The fiber diode tip moved anywhere in three direction which was enough to perform robotic tasks. A focusing lens with focal length 50 mm was fixed on the end effector of the robot which was further connected to the fiber tip. For easy harvesting, the focusing lens can be adjusted vertically with a tilt angle of $\pm 10^0$. The whole system is driven by a DC motor using a bearing structure. It was found that, drilling time was directly related to diameter of peduncle and inversely related to the laser power and incident angle.

Parisses and Marinis (2011) designed an autonomous robotic vehicle and developed a suitable gripper for harvesting sensitive agricultural products. The system consists of a mechanical robotic end effector with a set of four fingers, an electric motor, motor controller and control board. The batteries on the board supply power. Different types of fingers were tested to suit the overall geometry of the fingers and also different materials at the fruit contact area were checked depending upon the sensitivity of the crop.

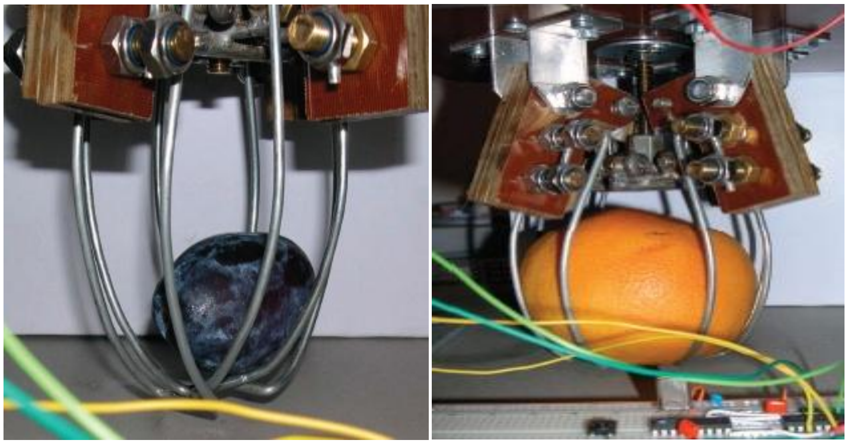


Figure 2.3 Fingers used to capture the fruits (Parisses and Marinis ,2011)

Bachche (2013) designed an end effector with a servo motor which was connected to big and small gears control the gripping and cutting system through computer. When the motor rotates, power was transmitted from the motor shaft to the big gear which controls or drives the gripper. Along with this, a small gear meshed with one of the big gear, drive a circular disc which is fixed on the other end of the end effector. A cutting scissor was attached to the circular disc, which start functioning with the rotation of disc. Due to the change in the gripping and cutting area, these gears offers variation in cutting speed that helps holding and cutting easy and thereby harvesting.

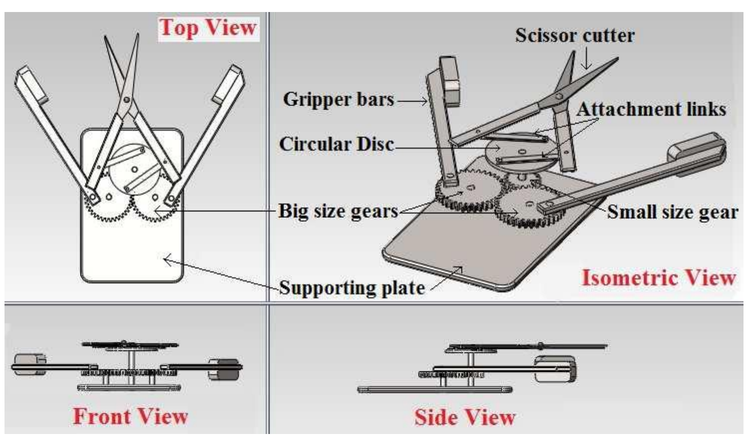


Figure 2.4 Designed end effector in different views (Bachche, 2013)

2.5 CUTTING OPERTAION

Cutting has been identified as one of the widely performed production method in separation of fruit from the parent plant. Cutting is done by using a blade or knife or cutter which is attached to the end effector. The pressure developed at the cutting edge of the plant due to the force applied through the knife will separate the cutting material into two sections, and hence cutting takes place. (Bosoi *et al.*, 1990)

2.5.1 Cutting Tool

Viswanathan *et al.,* (1995) conducted studies on effect of knife angle and cutting velocity on energy needed to cut cassava. They obtained a favorable value of cutting velocity, knife shear angle and bevel angle in comparison with cutting energy. Different shear angles of 30^0, 45^0, 60^0, $75\ ^0$ and 90^0 and bevel angles of 15^0,30^0, 45^0 and 60^0 were selected for the study. The cutting velocity selected for the study was 1.81 m/s, 2.68 m/s, 3.51 m/s, 4.90 m/s. Pendulum impact shear test apparatus was chosen for the study. The result revealed that precise cutting energy was noted to be in the least value when the bevel angle and shear angle were 30^0 to 45^0 and 63^0 to 75^0 respectively at a velocity of 2.5 m/s.

The experiments carried out by Ito *et al.,* (2014) measures the width of a rotary cutting tool edge by applying laser sensors. Intensity of the reflected light of the sensor was used for measuring the edge width which was smaller than laser beam diameter. Calibration method was used for obtaining the laser spot diameter using pin gauges. Thus, width of cutting edge that was formed on the cutting tool was measured and the accuracy was evaluated.

Schuldt *et al.,* (2016) analyzed the sharpness of blade for cutting. They transferred the dimensionless number BSI (blade sharpness index) concept to typical blades with typical geometry. Elastomers were used to determine the blade sharpness index. Wire cutting was used to determine fracture toughness. The result obtained indicates blade sharpness index as a linear function of tip radius of blade and force at initial cut. Also, blade sharpness index does not depend on cutting velocity, wedge angle and substrate.

2.5.2 Cutting Force

The cutting force required for harvesting the crop is mainly through shearing action of the cutting element. It can be done by the slicing action of a tool with sharp edge, tearing action of a tool with serrated edge, high velocity impact with single element or with scissor type tool. Either one or both of the two shearing elements pass each other to produce motion and hence detachment of the fruit takes place. (Sahay. 2010).

A harvester was designed, fabricated and tested for oil palm fruit bunches. A motor was fixed on a carrier machine which for smooth mobility throughout the orchard. Two DC motors were used for controlling the cutting unit and to provide smooth cutting action. Certain speed was set for the motor for successful cutting. Further decrease in motor speed caused an increase in both power and torque, which in turn created more force on the severing portion of the plant. (Shokripour *et al.*,2012)

A detailed explanation of determining the cutting force and torque required for severing the fruit stalk was given by Raghavendra and Naik (2015). A simple set up comprising of cutter, wooden block, standard masses, a pan and samplings were used as the experimental aids. This method was limited to some selected samples with larger peduncle length like mango, apple, guava and also for cutting small branches. The force and torque obtained from the experiment benefits in designing harvesting equipments.

2.5.3 Mechanical Properties of Crop

On the basis of beam theory, mechanical condition of bend stem of tomato plants were studied by Coutand and Moulia (2000). The tomato stem was considered to be a beam like structure and beam theory was applied. Spatial distribution of parameters like bending moment, stress, strain and curvature along the stems were determined. Longitudinal strain was measured using strain gauges or local mechanical methods It was found that, the integration of the longitudinal strain is responsible for the growth variation.

Esehaghbeygi *et al.,* (2009) conducted studies on shearing stress variation on wheat stalk for different levels of moisture content. The experiment was conducted at three different cutting heights with two types of cutting tool (smooth and serrated type). They revealed that the shearing stress were seen decreasing with decrease in moisture content and cutting height. Also, it was low using smooth type knife than the serrated type because of less frictional effect.

2.6 ADVANTAGES OF USING AGROBOTS

- Can work 24 hours a day without rest
- Easy adaptability and accuracy in the working environment
- Can work in very dangerous environments like poisonous chemicals, extreme high and low temperature conditions
- Like human being, they don’t get bored of doing same, repeated task continuously
- Productivity and quality of the product has increased considerably
- Chances of spreading diseases is very much less
- Labour charge can be saved
- Can be applied in rural areas for carrying out the operations
- Work effortlessly around rocks, ponds, trees and other obstacles

- If the driver’s seat, controls chamber and cabin can be eliminated, then machines can be made lighter and simpler.

(Gund and Bope, 2015; Gohil *et al.*,2013)

2.7 DRAWBACKS OF USING AGROBOTS

Despite of many positive applications, there are certain negative impacts also for this. They are:

- High initial cost is required
- Not liable
- It could alter the culture /emotional appeal of agriculture
- In certain situations, robots lack the ability to respond to any emergencies which may lead to improper and false responses
- Lack of decision making and thinking power
- It make people deskilled and lazy
- Cannot usually adapt to unusual and strange environment
- Not suitable for making complicated decisions
- It may cause injuries to human being, even death

(Gohil *et al.*, 2013; Gund and Bope, 2015; Tanuja *et al.*, 2015)

Materials and Methods

Chapter III

MATERIALS AND METHODS

This work aims in studying the mechanical and biometric properties of plants and fruits of cucumber and tomato which influence mechanical harvesting; so as to evolve a design for a mechanical harvesting system that can be used for WSN based technology. An attempt was also made to develop a laboratory model of the evolved design so as to analyze its functionality and operational parameters. The methodology adopted in the study and the materials used are discussed in this chapter.

3.1 CONCEPT OF WSN BASED HARVESTER

Wireless Sensor Networks (WSN) is one of the most emerging technologies used for monitoring the environment and communicating the information obtained from the monitoring. It has an advantage of large scale application, less power consumption, adaptability, maintenance etc. (Simon & Jacob, 2012). Apart from environmental monitoring, WSN has a wide application in the field of health, security, logistics, tracking, forest, geography, natural calamities and also in the field of agriculture. (Buratti *et al.*, 2009). For the past many years, there have been tremendous progresses in the technologies for agriculture .The use of WSN based technologies in agriculture is gaining attention especially for the application of pesticide and fertilizers. Its usage is extended for irrigation scheduling and other farming operations.

Researchers have found the application of WSN based technologies in protected cultivation methods like green house and polyhouse. Integration of WSN with polyhouse cultivation is a recent concept which leads to precision agriculture. Wireless technologies such as blue tooth, ZigBee, XBEE, gives point- to-multi- point communication facilities. WSN uses sensors for sensing the field and crop condition. These sensed data are processed under implant systems and this processed information is then sent to a decision centre. In the decision centre, the user/operator can use remote sensing techniques for giving further inputs and controlling the output unit. The output unit then performs the task given to it by the user. The output unit can be like unmanned vehicles, mechanical vehicles (Monisha and Dhanalakshmi, 2015).

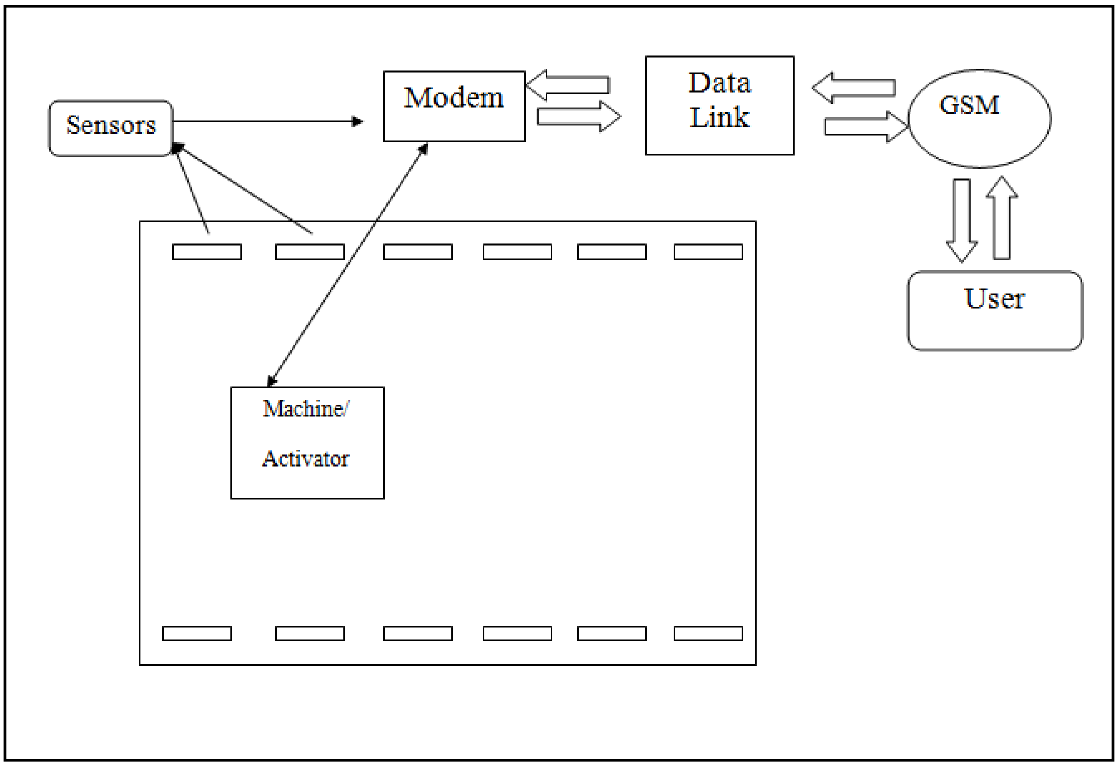


Figure 3.1 Block diagram of WSN technology inside polyhouse

The main objective of WSN system in polyhouses is to control the conditions inside the polyhouse based on the crop data sensed. The figure 3.1 gives a typical representation of the use of WSN based technology in the polyhouses. The integration of WSN in polyhouses for irrigation scheduling and controlling the environmental parameters within polyhouses has been an important research area in the recent scenario. The technologies for transferring sensed data from within the polyhouse and controlling actuators by the commands from the user are readily available. If proper sensing mechanism on the fruits to be harvested and an appropriate harvester which can harvest the fruit based on external command are available, the existing technology can be extended for harvesting operation. As the data communication system is already established, one of the major limiting factors in using WSN based technology for harvesting is the availability of harvester designs. Hence, the concept of a mechanical harvester suitable for WSN technology was evolved and this study, attempts to design a remotely operated mechanical system for harvesting operations.

3.2 STUDY SITE

As discussed in the introductory chapter, cucumber (*Cucumis sativus*) and tomato (*Solanum lycopersicum*) cultivated under protected environment were selected for this study as these are the most widely cultivated crops under protected environment. These crops are cultivated with trainers and supports. The location, its climatic conditions are discussed in the following sub sections.

3.2.1 Location

The crops for the study were planted in the polyhouse at Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, constructed and maintained by Precision Farming Development Centre (PFDC). The study location is situated between 10^0 52' 30" North Latitude and 76^0 East longitude.

3.2.2 Weather and Climate

Agro climatically, the study site comes under the border line of Northern Zone and Central Zone of Kerala. Major part of the rainfall in this region is obtained through South West monsoon. The average annual rainfall of this area varies from 2500 mm to 2900 mm. The average maximum temperature is 30^0 C and the average minimum temperature is 25^0C. The polyhouse selected for this study was 9.8 x 4.6 m^2.

3.3 STUDY SET UP

3.3.1 Polyhouse

Polyhouse cultivation is a new method in agriculture for attaining foothold in farming sector. This practice provides controlled and favorable environment to crops by reducing the dependency on rainfall and makes maximum use of land resource. The polyhouse structure is made of using GI pipes. The roofing and side covering is provided with a transparent UV stabilized low density polyethylene film of 200 micron thickness, which will create a micro climate inside the tent by regulating temperature, relative humidity and partially cutting Ultra Violet rays. Polyhouse are used to produce sensitive crops such as tomatoes, cucumbers, cherries, capsicum etc., which are susceptible to cracking. The specifications of the polyhouse used for the study are as given in Appendix I. The polyhouse were built in east west direction. The front view of the polyhouse is shown in Plate 3.1.

Plate 3.1 Front view of the polyhouse

3.3.2 Crop and Variety

Cucumber (*Cucumis sativus*) variety Hilton and tomato (*Solanum lycopersicum*) variety Anagha, a hybrid variety from Maharashtra Hybrid Seeds Co. Pvt Ltd were used for the study. Both these varieties are high yielding varieties and are most suited for polyhouse cultivation.

3.3.3 Cropping Pattern and Cropping System

The seedlings for planting was prepared in portray and then transferred to the field. Cucumber (*Cucumis sativus*) seeds were sown in a protray containing a mixture of cocopeat, vermiculate and perlite in 1:1:1 ratio. These seedlings were transplanted to the field 9 days after sowing to UV stabilized vegetable grow bags of size 20X20X35 cm. The distance between the center to center of the grow bags were kept at 20 cm. Tomato **(***Solanum lycopersicum)* seeds were sown in a protray containing mixture of vermi compost and sand in 1:1 ratio to a depth of 0.5 cm. These seedlings were transplanted to the field 18 days after sowing. Each grow bag was kept at a distance of 30 cm apart. Plate 3.2 shows the seedlings in the protray before transplanting in the plot.

3.3.4 Vine trainers / Supports

Plant trainers were used for cucumbers since it is a climber. Coir pith ropes were used as trainers for cucumbers. It was laid at a height of 2 m from the top of polyhouse and one rope was provided near each grow bag. In case of tomato, wooden sticks were used as supports. Wooden piece of around 1 m height was fixed in the grow bag, near the stem which gave mechanical support for the tomato plant.

Plate 3.2 Seedlings in protray before transplanting

3.4 BIOMETRIC PROPERTIES

For analyzing the growth pattern of the crop, 20 cucumber plants and 20 tomato plants were selected. The main crop growth parameters such as height of the plant, number of leaves, leaf length, leaf width, plant circumference, number of fruits, fruit lengths and fruit circumference were recorded.

3.4.1 Periodic and interval of observations

The biometric properties of the plants and the fruits were taken during the month of February 2016 to May 2016. The readings were taken with one week interval and it continued for about 70 days after transplanting, since the plants started to show yellowing of leaves, which indicates that the plants started to die and cannot be re-grown.(FAO, 2015)

3.4.2 Vine Length/ Plant Height

For cucumber plant, the length of vine was measured from the soil surface to the tip of the topmost leaf (youngest leaf) and for tomato; plant height was measured from the soil surface to the topmost leaflet using a measuring tape. The average value was worked out for further calculations.

3.4.3 Leaf Parameters

3.4.3.1 Number of Leaves

The total number of leaves on cucumber plant was counted. Tomato has a compound leaf structure. A compound leaf was selected randomly and the number of leaflets on that leaf was counted.

3.4.3.2 Leaf Length and Leaf Width

A leaf was taken randomly for cucumber plant for measuring the length from petiole to leaf apex. The length of the compound leaf was measured from petiole to the terminal leaf tip using a ruler for tomato plant. Also, the terminal leaflet length was measured. Width of randomly selected leaf was measured for cucumber plant. In case of tomato, width of the terminal leaflet on the compound leaf was taken.

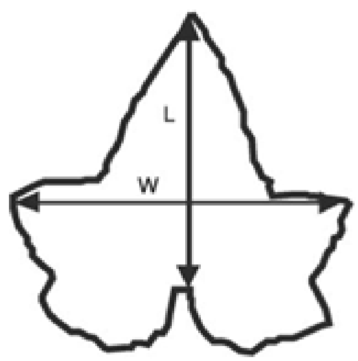


Figure 3.2 Diagram of cucumber leaf showing length and width measurements

(Blanco and Folegatti, 2003)

3.4.4 Plant Circumference

In case of cucumber, the plant circumference was measured at the axil where leaf parameters were measured and for tomato plant of tomato plant it was measured at the axil where the leaflet parameters were measured. Reading was taken using a measuring tape

3.4.5 Collision Parameter

The number of obstacles near the fruit peduncle in the path of the harvester was counted. Plant parts other than leaf area were considered as the obstacles while harvesting. Readings were taken weekly once when fruits were appeared.

3.4.6 Fruit Parameters

Fruit parameters like number of fruits, fruit length, fruit circumference, weight of the fruit, peduncle measurements were noted. Number of fruits per plant was counted and the average value was considered for further calculations. The fruit length was measured longitudinally from top to the bottom. Length of the fruits was measured using a measuring tape. The equatorial circumference of the fruit was measured using a measuring tape. The weight of the harvested fruit was measured using a digital balance.

The peduncle parameters like length and diameter of the peduncle of the harvested fruits were measured. The length was measured using a measuring tape and the diameter was measured using digital vernier caliper.

3.5 MATURITY INDICATORS

It is very much essential to identify a proper maturity indicator for the development of autonomous or semi autonomous harvesting equipment. This will aid in harvesting the crop at proper time. The data obtained from observing the biometric properties were screened for using as maturity indicators. The general considerations given for identification of the maturity indicators are:

- The method followed should be simple to carry out and it must be inexpensive.

- Generally, the tasks that can be performed either in the field or off the field are used.
- It is reliable that the indicating factor should be a measurement (objective) than an evaluation (subjective).
- It is better to follow a non destructive method of finding maturity of the fruit.
- Maturity indicators may vary from fruit to fruit even in same plant. But usually factors such as skin colour, size, weight, firmness, formation of abscission layer, disappearance of calyx etc are considered maturity indicators; either any one or a combination of many.

(Sudheer and Indira, 2007)

3.6 CROSS SECTION OF PEDUNCLE

The cross section of the peduncle was taken in the laboratory set up. Thin hand section of the peduncle was taken using a blade. Saffron coloring pigment was used to get the coloured section of the stem. The slide was prepared by selecting the most appropriate section. The magnified image was obtained through Leica microscope using 4 x lens. Image was obtained using a software- image analyser and the image was captured using Olympus camera.

3.7 CUTTING FORCE

The cutting force (firmness and toughness) required to cut the peduncle of cucumber was determined using TPA (Texture Profile Analysis). It was determined using a Texture Analyzer (TA.XT texture analyser, Stable micro systems Ltd.). It is a microprocessor controlled system which can be interfaced to a wide range of peripherals, including PC type computers. It is versatile and easy to use and is similar to a universal testing machine. The Texture Analyzer consists of two separate modules. The test bed and the control console (Key board). By connecting the texture analyzer to a personal computer installed with texture Exponent 32 software program (version 3.0). The texture analyzer can be controlled and the result can be obtained in a graphical format, find multiple peaks, measure gradients, areas, averages and then save the data on disc.

The texture analyzer measures force, distance and time, thus providing three dimensional product analyses. Force may be measured against set distance and distance may be measured to achieve set of forces. The probe carrier contains a sensitive cell. The load cell has mechanical overload and under load protection and an electronic monitoring system that stops the motor drive when an overload condition is detected. Distance and speed control is achieved using a step motor attached to a fine lead screw that winds the probe carrier up and down.

The cucumber with peduncles was marked for the different distance from apex to find out cutting force. Samples were placed on the heavy-duty platform of the texture analyser, positioned under the blade set probe and the test was carried out. The blade with 2.95 mm thickness and 30^0 angles was used for this test.

Plate 3.3 Texture Analyser

3. 8 DESIGN OF A MECHANICAL HARVESTER

3.8.1 Design considerations for the mechanical harvester

The design strategies and parameters for the design of mechanical harvesters were evolved based on the observations on biometric properties as discussed in section 4.1. For the proper harvesting and collection of the fruit, the harvesting unit should perform five different operations namely (1) Moving or guiding the harvesting unit through the crops, (2) Identifying the point of detachment of fruit from the plant, (3) Moving or positioning the cutting unit to the point of detachment of the fruit from plant, (4) Detaching the fruit from the plant and holding it, and (5) Conveying the detached fruit to the collection device. The optimal design of an autonomous or semi autonomous unit should have a proper recognition for locating the position of point of detachment of fruit from the plant. As the scope and objective of the present study was limited to design the mechanical harvesting unit, the design of the recognition system was not undertaken as a part of this study. The minimal requirements for the harvester for performing other operations listed above were considered for evolving the design. Based on the minimal requirements and literature review, the following three subsystems were identified for the mechanical harvester.

1. Moving system
2. Positioning system
3. Picking system

The design considerations for these subsystems are discussed in the following subsections:

3.8.1.1 Moving System

The system should be capable of making the harvesting unit to move between the plants. It should be able to hold the whole harvesting system. It needs to move freely between the plants and between the rows. The moving unit should have the stability while in operation. Because, there is a chance for the cutting unit to act like a cantilever along with the fruit in working condition. It should be robust to carry the whole weight of the equipment and at the same time it should be lightweight in order to avoid sinking in mud. Also, it should have the ability to overcome the obstacles inside the polyhouse like water pipes.

Based on the preliminary studies, it was found that different types of moving systems are available. It can be made of rails, pipes or tracks. According to Bachche (2013), the moving system comprised of crawling tracks. It requires special line tracing system that has to be laid inside the poly house, which makes more complications to work out. Another work by Van Henten *et al*., (2002) used a platform with linear struts on a reel. The structure is comparatively large in size and it makes it difficult to manage the work space inside the poly house. Difficulty for smooth guidance of the harvester between the crops was a major problem faced by Mandow *et al.*, (1996) and thus the size of the harvester was constrained to certain limit. Two methods of mobility of the harvester such as narrow platform and track rails were compared by Acaccia *et al.*, (2003).

The moving unit with two pairs of wheels was selected as a feasible model for the study with necessary modifications. The size of the base portion may be decided depending upon the row to row spacing of the crop. The harvester has to move through the spacing between the rows for harvesting operation. So, the size should be less than the row spacing to avoid the damages caused to the crops while operating.

3.8.1.2 Positioning System

A major term in connection with the design of harvester is degrees of freedom. For the smooth functioning of a harvester, at least the system must have three degrees of freedom in three different directions. The harvester should be free enough to move between the rows/plants to reach each individual plant. This will be provided by the moving system. Also, the harvester should have free movement in up and down direction for harvesting the fruits in a single plant. Also, for completing the harvesting operation of fruits at a particular distance, it should have a free lateral motion. Therefore, two sub units were identified for positioning system.

(a) Vertical Unit

Vertical unit determines the reaching ability of the harvester at different heights in a single plant. The height of the vertical unit depends upon the height of the plants grown in the polyhouse. In this study, the polyhouse height was concise to 4 m. The maximum height of the cucumber vine was limited to around 2 m (vine length exceeded 4m) and that of the tomato plant was around 1.5 m. Depending upon the height of the plant, the height of the vertical unit can be determined.

The function of the vertical unit is like the function of the manipulator of a robotic structure. A study by Parisses and Marinis (2011), introduced a manipulator system with a controlling program having automatic and manual controlling method. In manual control mode, operator can input the desired position values and control the manipulator. While in automatic mode, no human presence will interfere in the operation of manipulator and all the harvesting operations will be in automatic condition. As an initial step, adoption of fully automatic method was found to be difficult. Longo and Musato (2013) confirmed that CAD can also be used for controlling the manipulator. Harvesting machine for artichoke was designed and simulated under CAD environment. Graphical representation of artichoke was necessary to make for this. Preparation of the graphical design of each crop was found not to be an easy task. There are different mechanisms like rack and pinion mechanism, pneumatic mechanism, linear actuators and manipulators similar to human hands.

Out of this, the mechanism using linear actuators were found to be applicable for the designed harvester. Similar mechanism was adopted by Gay *et al.*, (2008) which used linear actuators for motion. This will help to give a simple and low cost moving mechanism. The adoption of linear actuator mechanism for vertical unit gives attention to individual plant operation, which required more time (Acaccia *et al.,* 2003).

(b) Horizontal Unit

Horizontal unit decides the maximum reaching ability of the cutter unit towards the fruit in a particular height. The length of the horizontal unit is determined based on row to row spacing. Also, it should have the ability to withstand the weight of the fruit without hanging effect. The fruit picking unit or the cutting unit can be attached to this unit.

De-An *et al.,*2011 describes joint structures for effective positioning in a three dimensional working space. The movements were controlled using pump lifting mechanism. Hayashi *et al.,* 2002 used a manipulator resembling human arm with 5 DOF for approaching the fruit. There are several mechanisms used for the manipulator like pneumatic system, rack and pinion system and linear actuator system. Out of this, linear actuator was considered to be the most suitable mechanism, for manipulator.

3.8.1.3 Picking System

The picking system consists of the cutting unit and gripping unit. The cutting unit detaches the fruit from the parent plant and gripping unit holds the fruit from without falling and helps to deposit the fruit to a safer point. It should satisfy the requirements like low maintenance, be approved with fruit stuffs, ease of cleaning, proper gripping and detaching of fruit. There are several types of fruit detaching technique like pneumatic type, electrical type and hydraulic type. The main thing to be considered while harvesting is the mechanical damages caused to the fruit and fruit peduncle. The cutting and grasping unit should be selected accordingly.

Considering all these factors, the cutting unit with cut and hold mechanism was used as the end effector. Sharp, wedge shaped blade with a wedge angle of 12^0 was used as the cutting tool. Bedford *et al.,* (1998) chose an end effector with blade since it gives a lesser amount of stress to the fruit to be detached from the plant. The size of the holding unit depends upon the diameter and length of the fruit peduncle. From the data given in Table 4.16 and 4.17, it is clear that almost all the peduncle lengths of both fruits lie above 1 cm. Hence, the holding unit with 1 cm width is selected. The diameter of cucumber peduncle is above 2 cm and that of tomato is above 1cm. Since the firmness of peduncle lies above 14 Kg, the peduncles will withstand the holding force of the holder without any damages..

3.8.1.4 Control Unit

A control unit is necessary for controlling the operations of whole unit. The motions in three degrees need to be regulated and controlled for the proper functioning of the harvester inside polyhouse. For base unit, the forward-reverse motion and the turning motion have to be regulated. For vertical unit, the up and down motion of the cutting unit has to be controlled. Similarly for horizontal unit, the to and fro motion of the cutting unit has to be managed. Regarding the cutting unit, the cutting action and holding action should be controlled.

3.9 PRINCIPLE

3.9.1 Longitudinal and Lateral Mechanism

The mechanism used for up and down motion of the harvester is referred as longitudinal mechanism. The mechanism used for side to side motion is mentioned as the lateral mechanism. The principle used for these mechanisms is linear actuators.

3.9.1.1 Linear Actuators

Linear actuator gives a straight line motion using a circular motion of an electric motor. It is widely used in industrial machineries, machine tools and in computer accessories like printers and hard drives and in many places where linear motion is needed. There are different types of linear actuators used like mechanical actuators, hydraulic actuators, pneumatic actuators and piezoelectric actuators. The actuator used for this study is mechanical actuators.

Mechanical actuator works on the principle of conversion of rotary motion of a motor to linear motion. The conversion can be done via simple mechanisms like screw type, wheel and axle type and cam type. The rotation of the electric motor is mechanically connected to rotate a threaded rod or screw using a gear. The rod has continuous helical thread with definite pitch. A nut having corresponding helical threads is threaded onto the rod. The nut is prevented from rotating freely with the rod, since it gets interlocked with the non rotating part of the actuator. Therefore when the rod is rotated using the motor, the nut will be driven along the threads. Depending upon the direction of the rotation of the rod or the screw, the direction of motion of nut can be determined. This motion of nut can be converted to usable linear motion by connecting necessary linkages to the nut. This mechanism can be used both for longitudinal and lateral movements.

3.9.2 Fruit Detaching Mechanism

Fruit detaching mechanism used for separating the fruit from the plant is cut and hold mechanism. The wedge shaped cutting tool will cut the fruit from the parent plant and a gripper with grooves made of fiber, just below the blade will hold the fruit firmly without slipping. The cutting blade can be connected to a motor using a cam, which transfers rotary motion of the motor to reciprocating motion of the cutting blade.

3.10 DEVELOPMENT OF A LABORATORY PROTOTYPE AND TESTING

Based on the subsystems identified and evolved design, a laboratory prototype was fabricated for analyzing the functionality. The components of the prototype are base unit, vertical unit, horizontal unit, cutting unit, control unit and DC motors. The prototype was developed with wired manual control for the positioning of cutting mechanism, detaching the fruit and for conveying the detached fruit.

3.10.1 Base Platform

The platform of the harvester is a frame made of mild steel angle of width 25 mm. The dimension of the frame is 450X450 mm. Two pairs of fiber wheels with a diameter of 100 mm are used for motion. The wheels are connected through a shaft. This forms the mobile platform of the harvester. Two parallel metal pieces are fixed on this frame upon which the base of the harvester is bolted. The base is made of galvanized iron square pipe of 250 mm thickness. The size of the pipe is 30X30 cm. Above the square pipe, a galvanized iron circle piece with a diameter of 15 cm is fixed. This comprises the base unit of the harvester. The horizontal and vertical unit of the harvester is mounted on this whole base portion.

Plate 3.4 Base Platform

3.10.2 Vertical Unit

The vertical unit for longitudinal movement consists of two threaded rod and a square pipe, mounted on the base portion. Mild steel threaded rod with 10 mm diameter and a square pipe of 2 cm is used for this. The height of the vertical unit is 2 m. Square pipe and threaded rod is bolted to a mild steel angle of 18 cm length at top and bottom using lock nut. The bottom side is welded to the base circle frame. Motor drive for giving the up and down motion is mounted at the top portion. The motor drive is transmitted to the threaded rods through gears. Big gear with 60 mm diameter is connected to the motor shaft directly. Small gears with 40 mm diameter are connected to the two threaded rods and are in mesh with the big gear. Two hexagonal threaded pipe of length 10 cm is fixed concentric on to the vertical threaded rod. A concentric square pipe is fixed on to the vertical square rod which is free to move up and down. These two hexagonal pipes along with the square pipe have to be in same line and are connected together using a galvanized iron sheet of length 10 cm and width 3 cm. The horizontal unit is bolted to this sheet.

3.10.3 Horizontal Unit

The horizontal unit for lateral movement consists of a threaded rod, galvanized iron channel, a motor and the cutting unit. A threaded rod of 0.5 cm diameter and 45 cm length is made to pass through the channel. Motor for giving drive is fixed on one end of the threaded rod. Both ends of the rod are locked using a lock nut. The motor shaft is connected directly to the threaded rod and supported using a clamp of 10 cm length, so that the rotary motion of the motor is transferred to the threaded rod. A square rod of length 12 cm extends out from the threaded rod upon which the cutting unit is connected. This extension helps to avoid the plant obstacle while harvesting and thus reduces the damages occurring to the plants. Another square rod is connected at an offset of 5 cm below the threaded rod for giving mechanical support to the horizontal unit and holding support to the cutting unit.

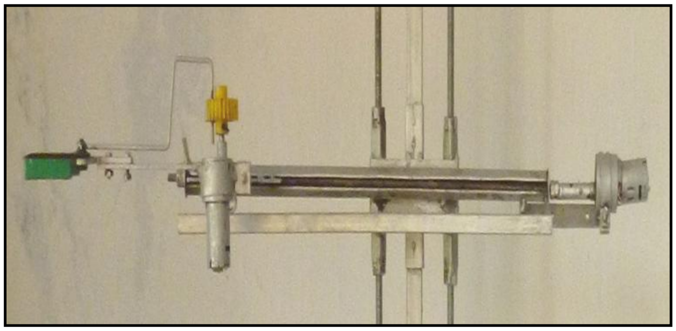


Plate 3.5 Horizontal Unit along with Cutting Unit

3.10.4 Cutting Unit

The cutting unit works on the principle of cut and hold mechanism. The unit consists of a cutting blade and a motor. The cutting blade is screwed on a metal piece of 12 cm length. At one end of the metal sheet, the motor for giving motion is connected. A gear with 40 mm diameter is connected directly to the motor shaft. The motor is clamped firmly to a square rod that extending from the horizontal unit. The gear and the cutting blade are connected using a connecting rod. Both the metal piece and the extension square rod together resemble an “L” shape on which the whole cutting unit is fixed. The cutting tool is wedge shaped scissor type curve blade which has very sharp, thin edge at one side of the blade and thick edge at the other blade. The fiber holding tool just below the cutting blade has grooves for proper holding. Cutting blade with cutting angle 12^0, blade thickness 1.63 mm (at the middle of the cutting edge) and gripper thickness 10 mm is used.

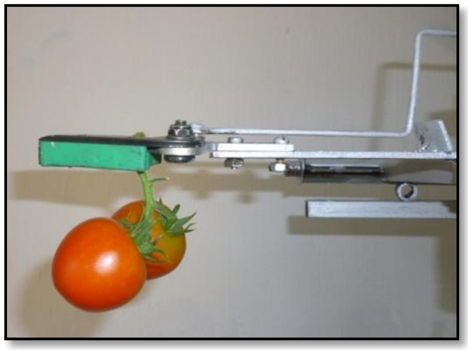


Plate 3.6 Cutting Unit

3.10.5 Control Unit

The control unit consists of a switch panel with four pairs of switches for controlling the motion of the motor. Each pair of switch is will give a forward and reverse motion for the movement. Three motors are used for giving three separate motions. The motor is connected to the controlling unit through single strand wires which is further connected to a cable. Switch is then connected to a power supply using an adapter.

3.10.6 Motors

Motor was used for giving mechanical power for base unit, vertical unit, horizontal unit and cutting unit. The forward and reverse motion for the base unit was given by the two motors that were connected to the front wheels of the base unit. The up and down motion for the horizontal unit that was attached to the vertical unit was given by a motor that was fixed at the top of the vertical unit. Similarly, the to and fro motion of the cutting unit that was attached to the horizontal unit was provided by the motor attached at the end of the screw thread of the horizontal unit. The cutting and holding operation of the cutting unit was powered by a motor that was attached at the cutting unit. The torque developed during the operation of the motor produces mechanical rotation and hence the motion.

3.10.7 Testing

The testing of the fabricated harvester was carried out in a laboratory set up. The cucumbers and tomatoes for testing were hung in the lab using a rope at different height. The motions of cutting unit in three different directions were checked and it was found functioning properly. The time taken for harvesting was found more and it can be solved by using threaded rods of higher pitch value.

Plate 3.7 Fabricated harvester prototype in the lab set up

Results and Discussions

Chapter IV

RESULT AND DISCUSSION

The work presented here is a study to investigate the suitability of using WSN based technology for harvesting crops especially in poly houses. The biometric properties of the crops that affect the mechanical harvesting were studied and are presented in this chapter. Based on the study of the biometric properties a basic design of a mechanical harvester, which can be suited to WSN based technology, is evolved.

4.1 BIOMETRIC PROPERTIES OF CROPS WHICH INFLUENCE HARVESTING

The biometric properties of the crops that affect the mechanical harvesting are discussed below.

4.1.1 Vine Length / Plant Height

Plant length (vine length) directly affects the design of the harvester. It determines the height of the mechanical harvester. Since cucumber is a climber, it will climb over a large distance. To certain extend the height can be controlled by adopting special plant training method like umbrella system or tree trellis system. In polyhouse, the plant height can be controlled with respect to the height of structure. While in open field, the chances of spreading of the vine irrespective of the trainer are more. In both the cases, plant height influences the harvesting operation of the harvester. Gay *et al.*, (2008) reported that the size of the harvester should be foreseen while designing the harvester, depending upon the height of the crop.

The data on vine length of cucumber plant and height of tomato plant are presented in Figure 4.1. Observations revealed considerable changes in the height of plant along with the crop growth. At the first stage of harvesting on 35th day after transplanting, the minimum length of the cucumber vine was noted as 1650 mm and the maximum value was 2100 mm. The average value was observed to be 1887 mm.

Table 4.1 Vine length of cucumber plant in the crop period

Vine length (mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	177	407	940	1525	1887	2150	2625	3055	3500	3965
Max.	220	600	1400	1900	2100	2400	2900	3300	4000	4300
Min.	140	300	650	1250	1650	1900	2300	2600	3000	3600

After 70 days of transplanting, the length of vine exceeded 4000 mm as the greatest value. The minimum height on the same day was recorded as 3600 mm with a mean value of 3965 mm.

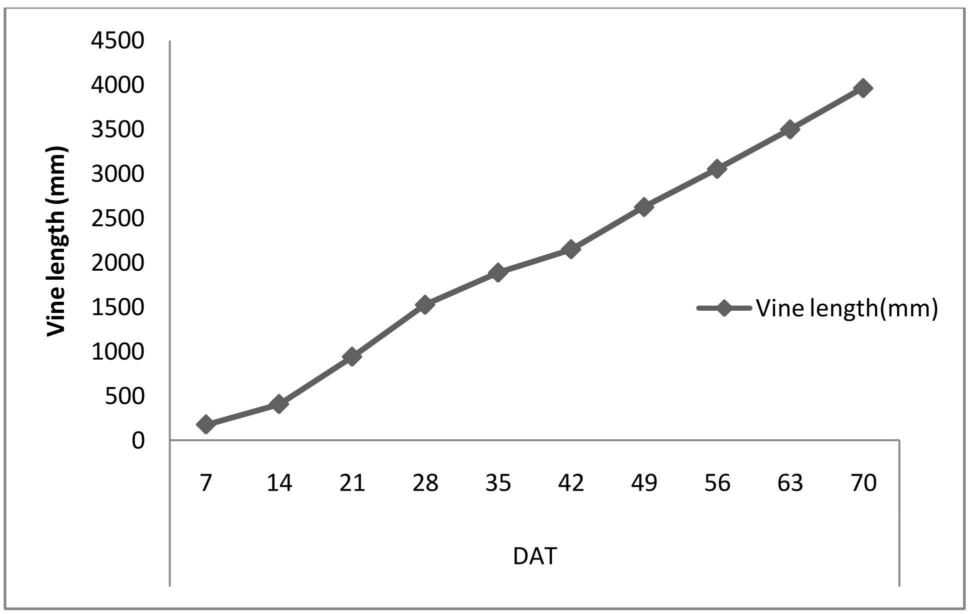


Figure 4. 1 Vine length of cucumber plant on different DAT

In case of tomato plant, the mean height observed on the 7th day after transplanting was 244 mm with a maximum and minimum value of 320 mm and 120 mm respectively. It then projected to a maximum length of 1150 mm and a minimum value of 1050 mm.

Table 4.2 Plant height of tomato during the crop period

Height of plant (mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	244	378	580	840	874	956	984	1020	1070	1100
Max.	320	490	700	960	1000	1150	1100	1100	1500	1150
Min.	120	170	250	480	560	730	850	950	970	1050

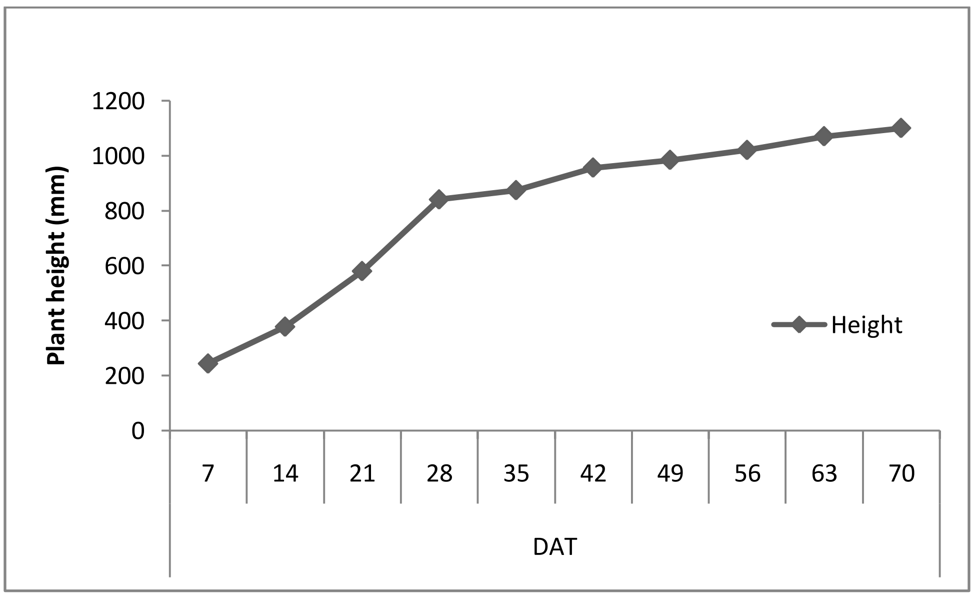


Figure 4.2 Height of tomato plant on different DAT

4.1.2 Leaf Parameters

4.1.2.1 Number of Leaves

The number of leaves affects the performance of the harvester. Leaf density in the working area of the machine decides the presence of obstacles in the operation.

In this case, since there is no artificial vision system used for identifying the objects, this parameter has a role in identifying and locating the fruit position. A study by Burks *et al.,* (2005) reveals the importance of the working space of the machine. In spite of fruit related problems, locating the fruits that is occluded by the leaves were identified as a major issue that affects the efficiency of the harvester.

Plate 4.1 Tomato plant after 7 days of transplanting

Table 4.3 Number of leaves of cucumber plant during the crop period

Number of leaves	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	6	9	24	44	68	97	115	118	126	124
Max.	6	12	30	62	102	118	124	132	140	138
Min.	5	7	11	25	28	46	68	72	80	82

An examination of the data presented in Table 4.3 revealed that during the first observation on 7th day after transplanting, the maximum and minimum number of leaves observed were six and seven respectively for cucumber plants. While on 70th day after transplanting, the maximum number was around 138 and minimum was observed as 82 with a mean value of 124 numbers of leaves.

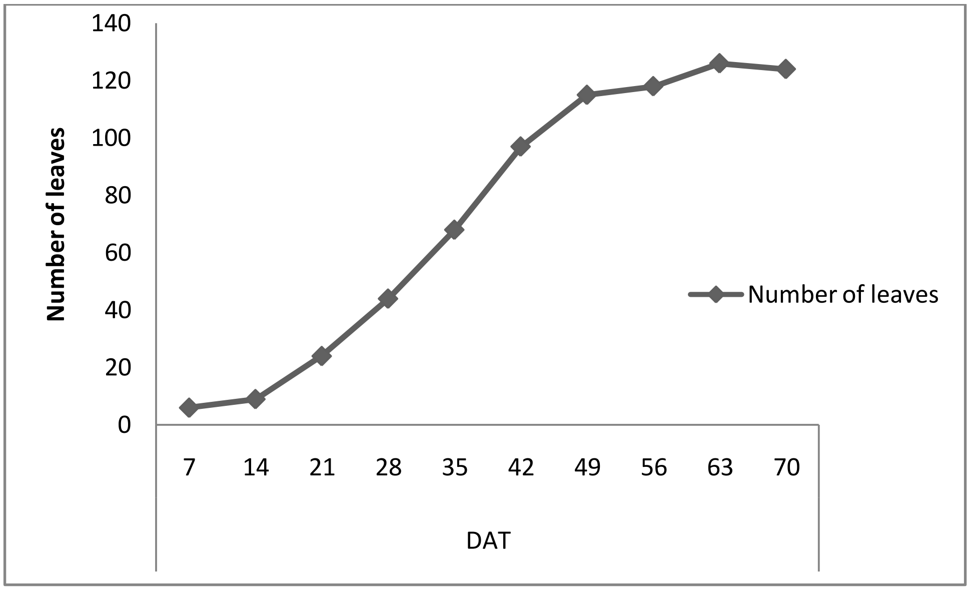


Figure 4.3 Number of leaves of cucumber plant on different DAT

Table 4.4 Number of leaflets on compound leaf of a tomato plant during the crop period

Number of leaflets on compound leaf	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	6	9	11	10	9	7	9	8	9	8
Max.	9	11	15	11	9	11	11	11	7	9
Min.	5	5	9	9	9	5	5	5	9	7

A modest change was observed in the number of leaflets on a compound leaf of tomato plant. The number of leaflets was in a range of 9 and 11. The maximum value was recorded as 15 and minimum value as 5.

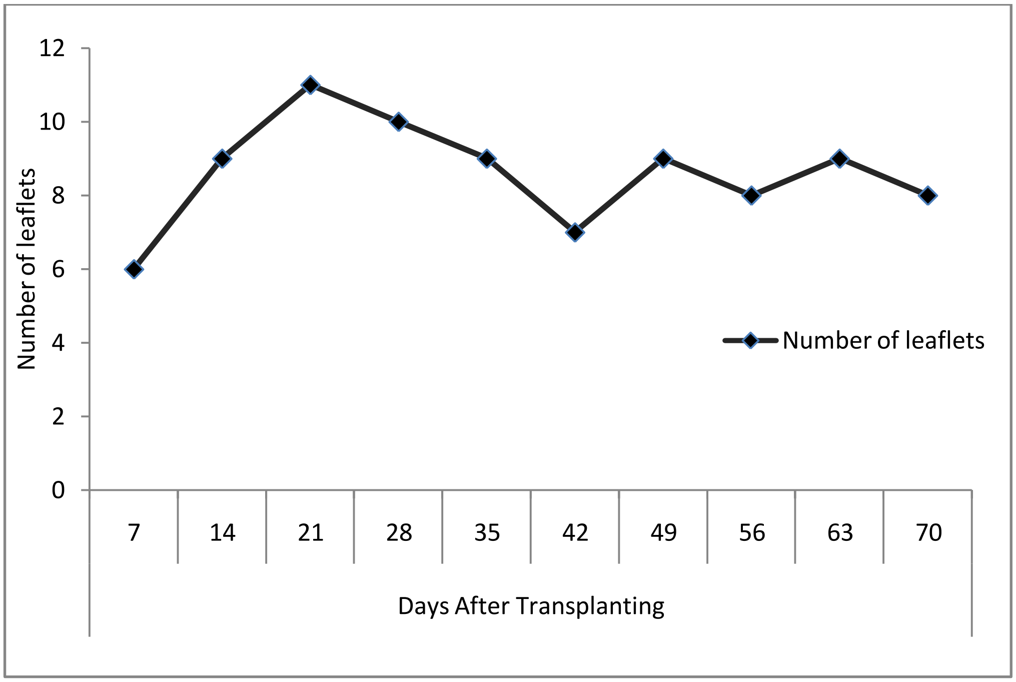


Figure 4.4 Number of leaflets on a compound leaf of tomato plant on different DAT

4.1.2.2 Leaf Length and Leaf Width

Table 4.5 Leaf length of cucumber during the crop period

Leaf length (mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	100.5	141.5	175	187.7	194.5	196.3	220	226.3	229.6	231.5
Max.	115	165	220	212	225	225	235	238	238	240
Min.	90	110	140	155	160	164	200	210	220	220

Length of leaf and width of leaf affects the leaf canopy of a plant. This in turn affects the performance of the harvester. Burks *et al.*, (2005) suggested a thin leaf canopy for better result of the performance of the harvester. They found out it was difficult to harvest a fruit located in the interior of the leaf canopy.

(a) (b)

Plate 4.2 Tomato (a) without and (b) with leaf as an obstacle

(a) (b)

Plate 4.3 Cucumber (a) without and (b) with leaf as an obstacle

From the Table 4.5, it was inferred that there was a substantial increase in leaf length of cucumber plant with growth. Also it was observed with a maximum value of 115 mm and a minimum of 90 mm and the mean value was 100.5 mm on 7th day after transplanting. At the 70th day after transplanting, the maximum value was noted as 240 mm, minimum value as 220 mm and the mean value as 231.5 mm.

Table 4.6 Leaf width of cucumber during the crop period

Leaf width(mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	108	167.5	209	232.4	240.4	242.4	247.3	248	229.6	246.6
Max.	115	185	220	240	275	276	258	258	238	252
Min.	100	130	150	205	210	208	230	235	220	240

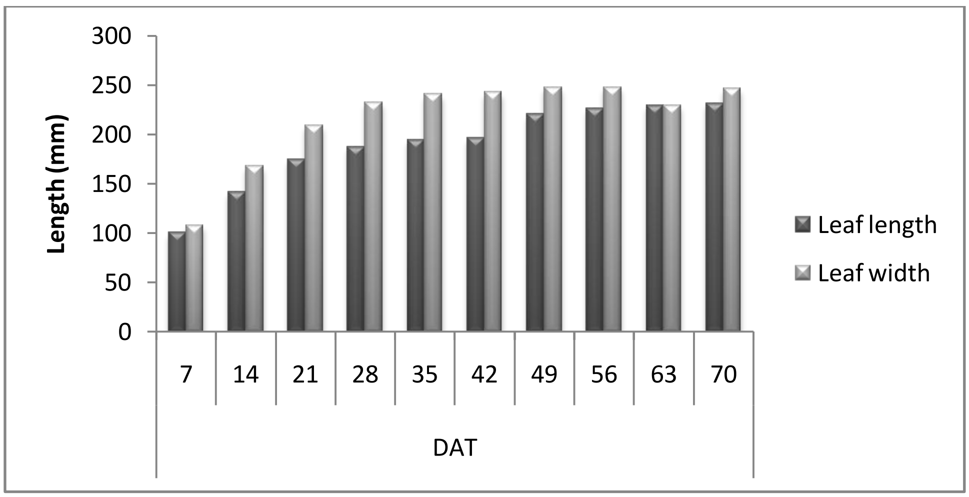


Figure 4.5 Average leaf length and leaf width of cucumber leaves on different DAT

Leaf width increased with increase in number of days in the initial days and had a slight decline in the final observations (Table 4.6). The maximum and minimum value was observed as 115 mm and 100 mm respectively with a mean leaf width of 108 mm. The last observation was found to have a maximum leaf width of 252 mm and minimum leaf width of 240 mm. The mean leaf width recorded in the last observation was 246.6 mm.

Table 4.7 Terminal leaflet length of tomato during the crop period

Terminal leaflet length(mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	26	49.6	62	73	72.2	79.6	78.6	80	82	82.6
Max.	32	70	70	90	78	90	93	95	95	90
Min.	15	15	50	55	65	60	65	65	70	78

The maximum and minimum value of terminal leaflet length of the tomato plant changed respectively from 32 mm and 15mm at 7th day after transplanting to 90 mm and 78 mm at 70th day after transplanting. The mean value on first observation was 26 mm and 82.6 mm on last observation.

Table 4.8 Terminal leaflet width of tomato during the crop period

Terminal leaflet width (mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	22.8	27.4	33.8	37	36	41.2	41	43	41	40.6
Max.	28	35	40	45	40	50	50	50	45	45
Min.	12	12	30	30	35	35	35	35	35	38

Terminal leaflet width of the tomato plant was recorded as 28 mm (maximum), 12 mm (minimum) and 22.8 mm (mean) in the first observation on 7th day after transplanting. The final observation was reported with a maximum leaflet width of 45 mm, minimum leaflet width of 38 mm and mean leaflet width of 40.6 mm.

Table 4.9 Compound leaf length of tomato during the crop period

Compound leaf length (mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	115	194	580	269.6	257	249.6	238.6	252	243	250
Max.	140	250	700	305	295	295	278	295	270	260
Min.	55	75	250	215	220	210	210	210	215	240

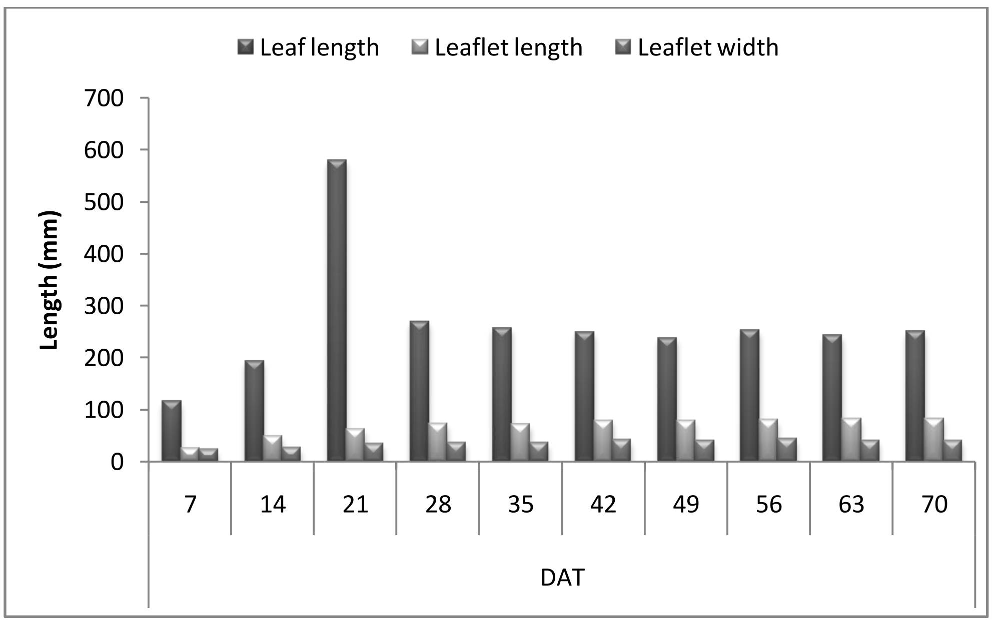


Figure 4.6 Average length of compound leaf, terminal leaf and width of terminal leaves of tomato on different DAT

4.1.3 Plant Circumference

Cargill (1983) pointed out that the uniform shape and size of the plant in a nursery or orchard will help to improve the efficiency of the harvester. Similar findings were explained by Burks *et al.,* (2005). The fruit detaching mechanism will interact directly with the fruit and plant parts. The cutting tool can be designed by considering the circumferential area of the stem in order to reduce the damages occurring while harvesting.

Table 4.10 Plant circumference of cucumber plant during the crop period

Plant circumference (mm)	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	15.1	19.8	24.9	26.6	28.2	30.3	35	36.2	36.8	38.4
Max.	16	21	30	22	30	34	38	40	40	42
Min.	14	18	20	33	23	28	28	32	334	34

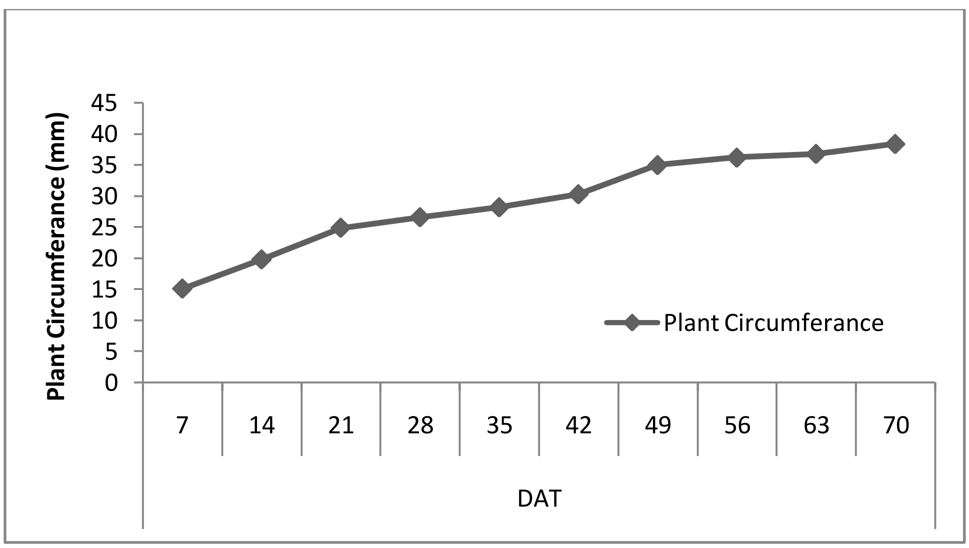


Figure 4.7 Average circumference of cucumber vine on different DAT

By analyzing the data given in the Figure 4, plant circumference of the cucumber vine increased gradually. The mean value varied from 15.1 mm to 38.4 mm in the first and final observation respectively. Least value of circumference of the vine was 14 mm and the larger value was recorded as 42 mm.

Table 4.11 Plant circumference of tomato plant during the crop period

Plant circumference	Days After Transplanting									
	7	14	21	28	35	42	49	56	63	70
Mean	16.4	23.2	30	37.2	35.6	35.6	37.8	42.6	34.4	40.6
Max.	18	30	37	40	45	42	40	48	42	45
Min.	15	17	21	33	30	35	35	35	30	38

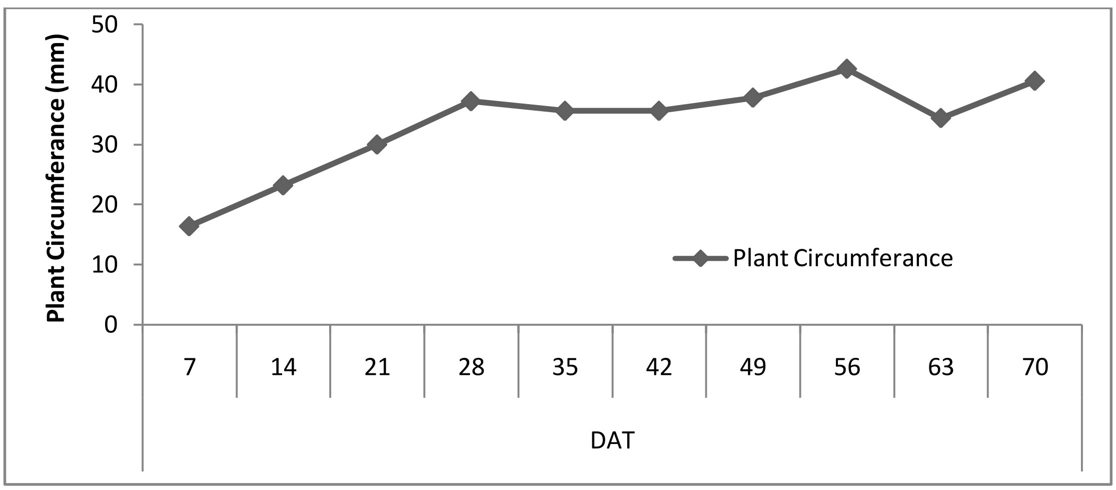


Figure 4.8 Average circumference of tomato stem on different DAT

In case of tomato plant, the plant circumference had a significant increase from a mean value of 16.4 mm to 40.6 mm. The minimum value of plant circumference observed was 15 mm and the maximum value recorded was 48 mm.

4.1.4 Collision Parameter

The obstacles in the path of the cutting tool around the peduncle of the fruit were taken excluding the leaf area. This was done to know the amount of damages that will cause to the plants while harvesting using the harvester. Fernandez *et* *al.*,(2014) states the importance and advantages of detecting and localizing the plant parts other than fruits, that could interfere the smooth motion of robotic structure.

Table. 4.12 Obstacle gradient along harvester path

Crop	Cutting tool position			
	Below 1 cm	Between 1 - 2cm	Between 2 - 3cm	Between 3 - 5 cm
Cucumber	6	5	3	2
Tomato	7	3	1	1

It was seen that, majority of the obstacle were seen at a distance below 1 cm from the fruit peduncle in the path of the cutting tool. This reveals that, the probability of occurrence of plant damages is around 40 percent for cucumber and 60 percent for tomato while harvesting.

4.1.5 Fruit Parameters

The fruit parameters like number of fruit per plant, mean fruit length and circumference of both cucumber and tomato are discussed below.

4.1.5.1 Number of Fruits

A study conducted by Burks *et al.*, (2005) reported that the number of uniform sets of fruits on a particular area helped to locate the fruit easily and also, the harvester worked with maximum productivity when the number of fruits in a specified work space was more. Similarly, Manolis *et al.*, (2008) and Fernandez *et al.*,(2014) revealed that the operation of gathering fruits will be less difficult for harvesting equipment that concentrated on individual plant than collective plant operation. This was because, individual plants bear the fruits in a limited area, which makes the number of fruits per working area more.

Table 4.13 Number of fruits on cucumber and tomato plant at different days after planting

Number of fruits	Days After Transplanting						
	28	35	42	49	56	63	70
Cucumber	2	9	13	18	19	16	22
Tomato	5	11	14	18	23	28	26

Maximum numbers of fruits in selected set of plants were found out as 2 in cucumber and 5 in tomato on 28 days after transplanting. In case of cucumber plant, the number of fruits increased gradually with the growth of plant till 56th day after transplanting. Individual plant was recorded with 22 cucumbers on 70th day after transplanting.

Similar trend was also seen in case of tomato plant. The number of tomato fruit on individual plant was recorded with a maximum value of 28 after 63 days of transplanting and a minimum value of 5 after 28 days of transplanting.

4.1.5.2 Fruit Length and Fruit Circumference

The length and circumference indicates the size of the fruit which will directly affect the harvesting operations. The weight holding capacity of the cutting unit is directly influenced by the size of the fruit. The volume of the fruit collector is also determined by the fruit size. Coppock *et al.*, (1969) mentioned the relevance of fruit size while harvesting using mechanical harvester.

The fruit parameters like average fruit length and equatorial fruit circumference of cucumber showed a modest change. A minimum length of 160 mm was observed on the harvest on 42 days after transplanting and a maximum length of 185 mm was observed on the harvest on 49 days after transplanting.

Regarding the equatorial circumference of the cucumber, a maximum value of 160 mm and a minimum value of 145 mm were noted for the harvested cucumbers

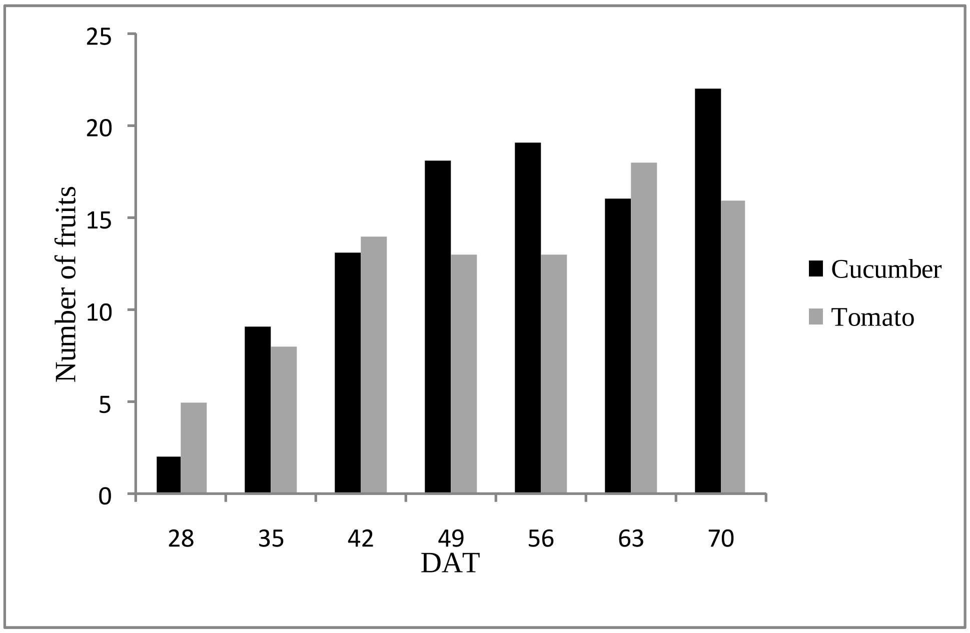


Figure 4.9 Average numbers of fruits on cucumber and tomato plants on different DAT

Table 4.14 Average value of fruit length and circumference of cucumber

Mean value	Days After Transplanting						
	28	35	42	49	56	63	70
Fruit length(mm)	175	165	160	185	165	180	175
Fruit circumference(mm)	155	150	145	160	148	165	160

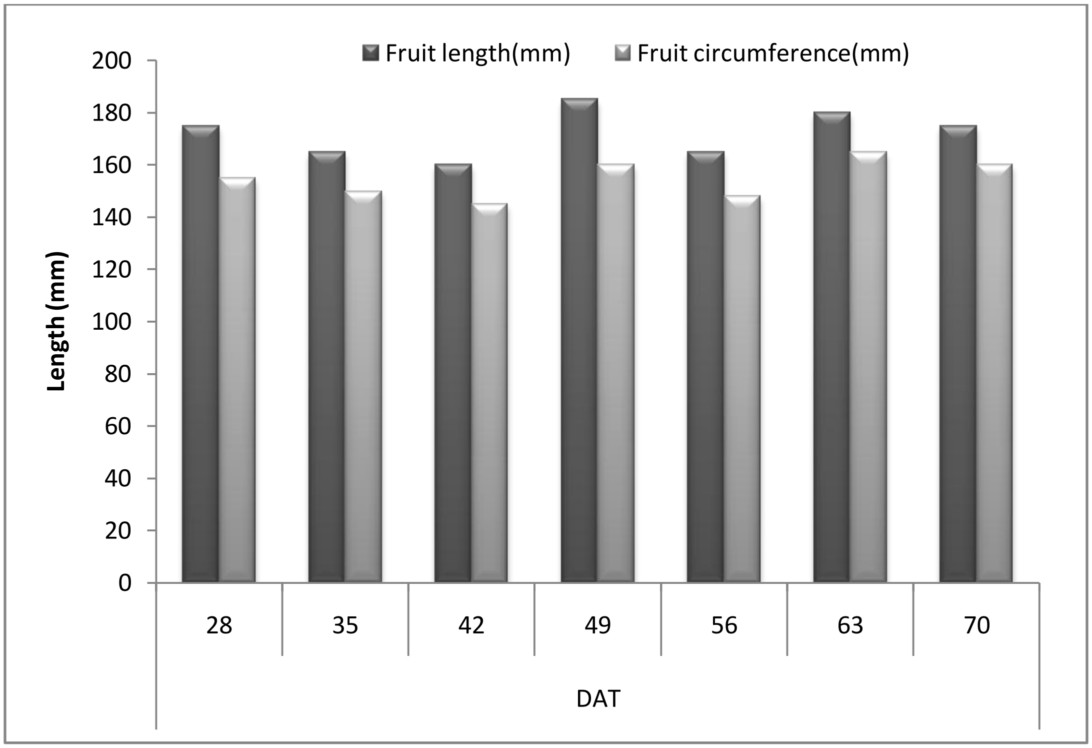


Figure 4.10 Fruit characteristics of cucumber on different DAT

Table 4.15 Average value of fruit length and fruit circumference of tomato

Mean value	Days After Transplanting						
	28	35	42	49	56	63	70
Fruit length(mm)	20	25	35	50	60	65	65
Fruit circumference(mm)	45	75	110	120	145	140	145

Since tomato has an oblate shape, the equatorial circumference of the fruit was greater than the fruit length. Fruit length and fruit width was seen least in the initial observations and it was shown the maximum value in the final observations.

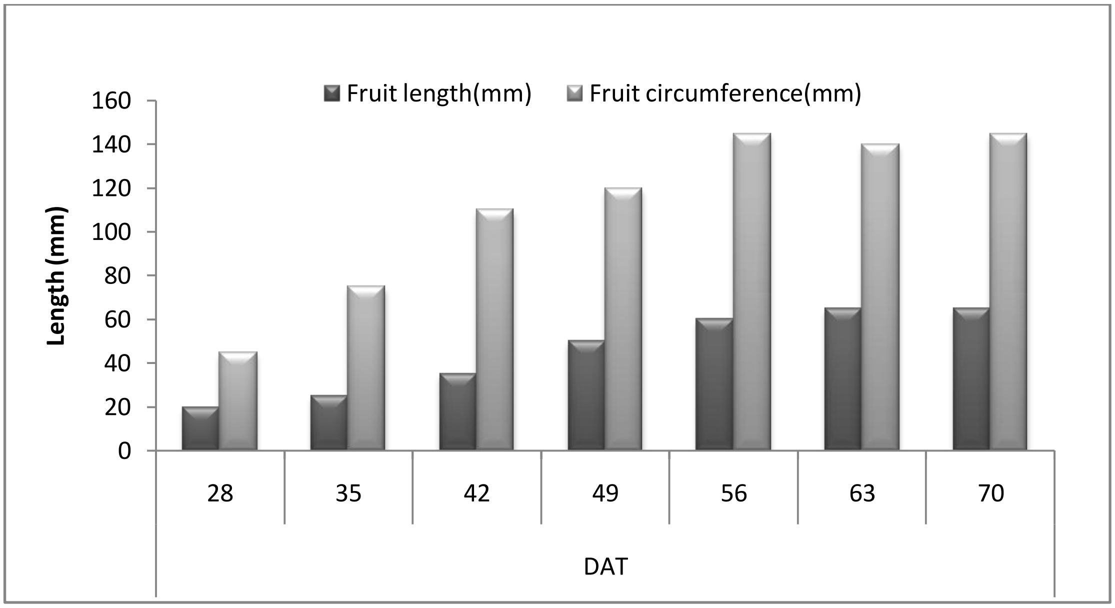


Figure 4.11 Fruit characteristics of tomato on different DAT

4.1.5.3 Peduncle Parameters

Table 4.16 Peduncle dimensions of cucumber

Sample No.	Cucumber weight (gm)	Peduncle length (mm)	Average peduncle circumference (mm)
1	113.24	53	3.53
2	299.70	22	3.03
3	275.30	35	3.25
4	217.10	55	2.66
5	203.60	32	2.59
6	178.40	35	3.13
7	180.40	44	2.66
8	164.30	25	3.33
9	197.30	53	2.91
10	159.20	22	2.48

The peduncle length and circumference have direct role in determining the cutting operation. Weight of the fruit, peduncle length and peduncle diameter are seen varying independently. Out of the selected samples, the highest peduncle length was noticed to be 55 mm and the lowest length was 22 mm. Likewise, the peduncle circumference showed up a maximum value of 3.53 mm and minimum value of 2.48 mm. Compared to the peduncle length of cucumber, tomato has shorter peduncles. This makes some inconvenience in the harvesting operation. The shortest value recorded for the peduncle length for the selected samples was 18 mm and the longest was 25 mm. Peduncle length is an unavoidable factor to determine the cutting portion. It decides where to make the cut, for detaching the fruit from the plant.

Deen *et al.*, (1966) and Burks *et al.*, (2005) mentioned the importance of proper harvesting with and without the presence of peduncle after harvesting. If the peduncle length is too short, mechanical harvest will be a failure. Also, fruits harvested along with the peduncle have got more market value because of its appearance.

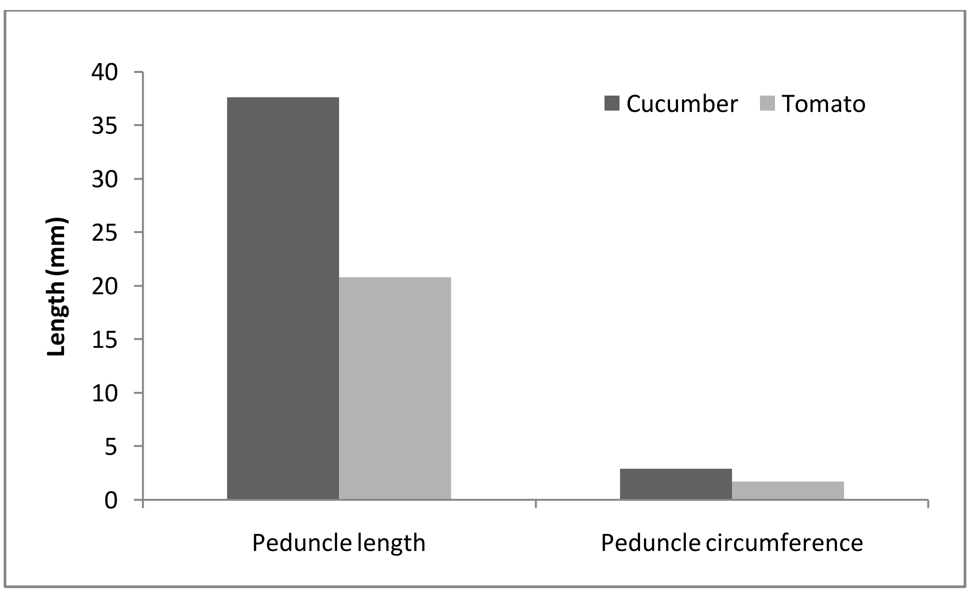


Figure 4.12 Peduncle dimensions of cucumber and tomato

Table 4.17 Peduncle dimensions of tomato

Sample No.	Tomato weight (gm)	Peduncle length (mm)	Average peduncle circumference (mm)
1	31.80	18	2.07
2	43.54	23	1.88
3	48.37	21	2
4	35.50	19	1.94
5	33.32	25	1.47
6	46.50	20	1.47
7	39.73	18	0.97
8	43.58	19	1.95
9	46.44	22	1.89
10	38.25	23	1.9

4.2 FACTORS AFFECTING CUTTING

Cutting has been identified as one of the important production methods. Depending upon the mechanical and physical properties of the material to be cut, geometry of the cutter blade and the nature of cutting process were determined.

4.2.1 Blade Parameters

Most of the operational part of a cutting element has one sided wedge shape. Blade parameters like blade thickness, wedge angle, blade shape, edge thickness, edge smoothness etc, will affect the cutting ability of the cutting tool. Burks *et al.*,

(2005) pointed out a method to detach the fruit using a sharp blade and justifies that the fruit damages will be less if we use this method.

4.2.1.1 Wedge Angle

Wedge angle is the angle of the cutting portion of a cutting tool. It is measured between the center of the blade and the bevel or flat cut by the sharpening surface. Smaller the angle of wedge, lesser will be the force required for cutting and resistive force offered by soft materials like peduncle. The wedge angle of the cutting blade used for the harvester is 12^0.

4.2.1.2 Edge Thickness

Edge thickness determines the sharpness of the cutting blade. An edge is considered to be sharp if the thickness comes under a few thousands of an inch. Ideal edge thickness is considered as zero when the edges come together. Cutting will be smooth if the edge is sharp and it effects the slicing action of the cutting tool.

4.2.1.3 Blade Thickness

Blade thickness affects the cutting and slicing action significantly. Irrespective of the sharpness of the cutting edge, blade thickness also has a major role in cutting process. Blade thickness of the cutting blade used for the harvester at the flat side is 3.03 mm and at the middle of the cutting edge is 1.63 mm.

4.2.1.4 Blade Shape

Shape of the blade is determined by the type of the function that the blade has to do. Generally, straight edge blades are confined for slicing action and curve type blades for cutting action. Cutting blade with curve shape is used for this harvester.

4.2.2 Cell Structure of Cutting Material

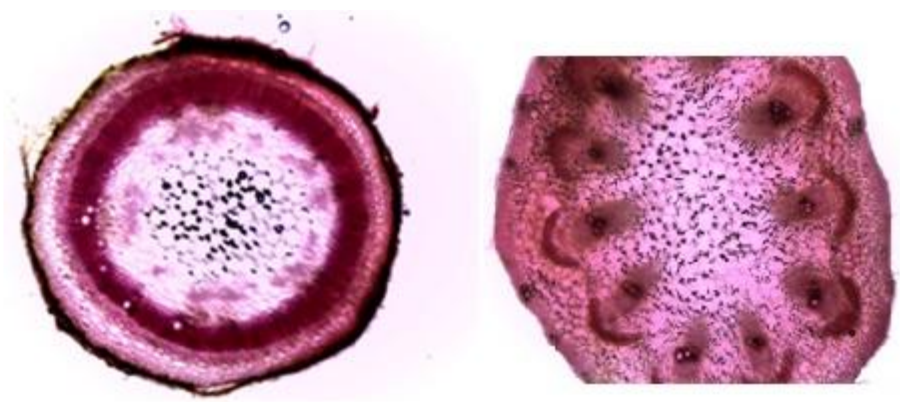
Cutting is done using a knife or cutter blade which has either flat or wedge shape. The force applied to the cutting blade results in a pressure at the cutting portion against the material; here the material refers to the fruit peduncle. This pressure leads to the breakage of the bond between the plant materials. Hence separation takes place and hence two cutting planes are formed. (Bosoi *et al.*,1990)

The peduncle of the crop consists of cells which are well arranged in a distinct manner to form a tissue. Presence of fibro vascular bundle of tissue makes the peduncle structure strong and reinforced. Hence, cutting the peduncle causes the destruction of fibro vascular fascicles. In monocot plants, the fibro vascular structures are spread evenly over the entire cross sectional area. In this type, the cutting tool has to pass through the entire cross sectional area to get the cutting done. While in dicot plants like cucumber and tomato, the fibro vascular bundles are seen only at the periphery of the peduncle and hence cutting has to take place only at this peripheral side.

4.2.2.1 Harvesting Stage of the Crop

Fruits can be classified into climacteric and non-climacteric fruits. Climacteric fruits ripen even after separating it from the parent plant. While non climacteric fruits can be harvested only after achieving the ripening stage. The changes in presence of ethylene production and cell respiration are the major reason for this classification.

Since tomato is a climacteric fruit, the ripening may happen even after harvesting. The harvesting stage of tomato depends upon the purpose and market distance from the orchard. Mainly it can be harvested in four different stages, depending upon the external colour appearances. First stage is the green colour stage in which mature raw tomato is harvested, generally for distant market sales. In the next stage, the green colour will change into pinkish red at the blossom end. They are taken to the local market. Next stages are the ripen stages, in which the softening of fruit begins and almost all the surface changes to red colour. The last harvesting stage is the fully ripen stage in which the tomato fruit will acquire maximum colour and softness.



(a) (b)

Figure 4.13 Cross sectional view of (a) Tomato (b) Cucumber peduncle

Cucumber is a harvested based on observing external appearance like size and colour. Depending upon the variety of the cucumber, the size may differ. The best time to harvest cucumber is when the colour attains uniform green.

4.2.3 Cutting Force

The cutting force required for cutting the peduncle of cucumber and tomato was obtained in terms of firmness from the texture analyser data.

The force required for cutting the peduncle was determined using a texture analyser. The cross section of the peduncle of mature cucumber was seen as a typical dicot stem, with ovate structure. Definite numbers of vascular bundles which are bicollateral were seen with xylem and phloem. The average force required for cutting the mature cucumber peduncle was obtained as 14.53 kg (142.44 N).

Table 4.18 Force required for cutting the peduncles of cucumber

Sample No.	**Diameter (mm)**	**Force (kg)**
1	4.42	14.16
2	3.29	14.06
3	3.29	15.54
4	3.49	14.98
5	2.54	14.39
6	3.15	14.10
7	2.67	14.76
8	3.22	14.65
9	3.18	14.32
10	4.22	14.39

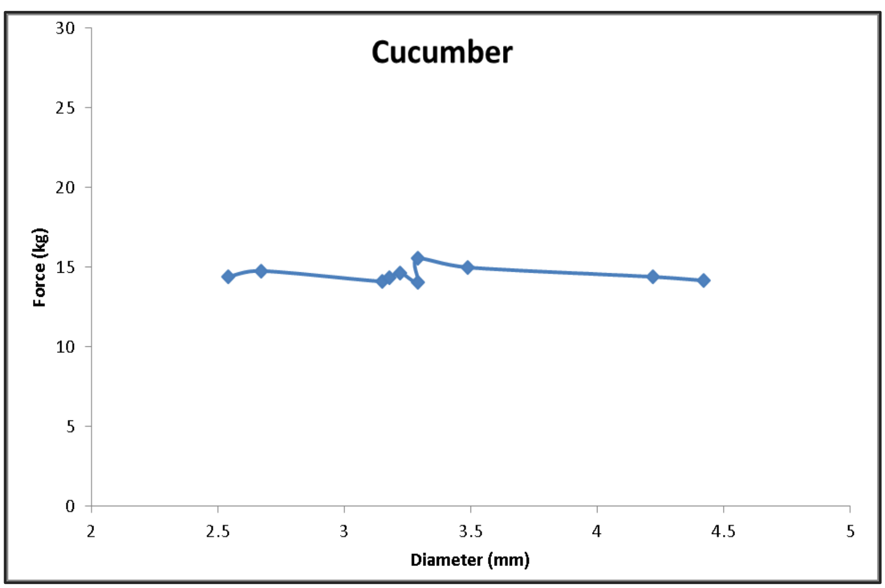


Figure 4. 14 Cutting force of cucumber peduncle

Table. 4.19 Cutting force for cucumber peduncles harvested on different days after flowering

Days after flowering	**Force (Kg)**
4	14.29
6	14.32
8	14.36
10	14.53

Also, there was no comparable variation in the force required for cutting the peduncle of cucumbers which was harvested on different days after flowering. A slight change was observed with 14.29 Kg and 14.53 Kg force for cutting the cucumber peduncle which was harvested four days after flowering and 10 days after flowering, respectively.

Table 4.20 Force required for cutting the tomato peduncles

Sample No.	Diameter (mm)	Force (kg)
1	2.34	16.02
2	1.8	15.04
3	2.07	15.17
4	1.93	15.04
5	1.91	15.70
6	1.86	16.36
7	1.96	16.14
8	2.03	15.32
9	1.98	15.43
10	1.87	16.79

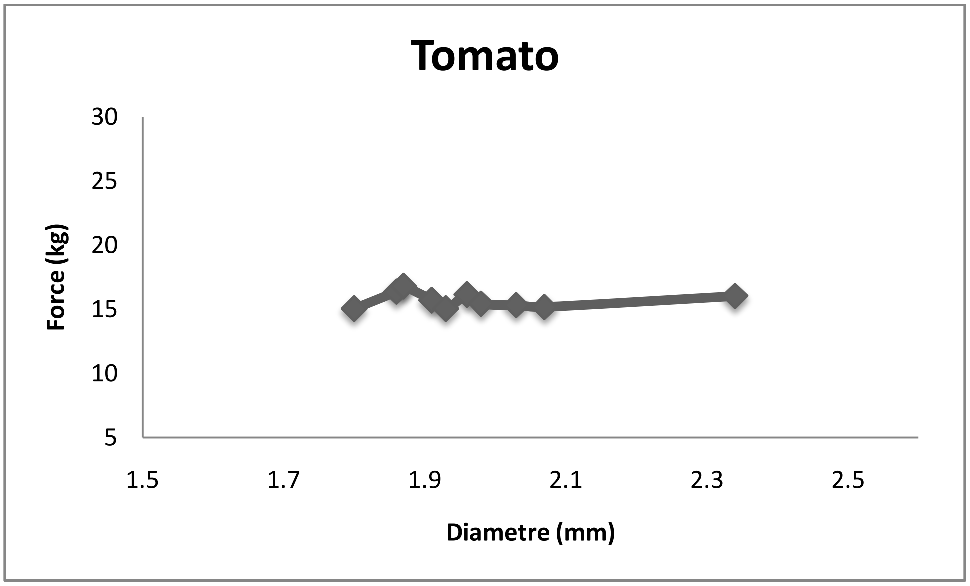


Figure 4. 15 Cutting force of tomato peduncle

In case of mature tomato peduncle, the force required for cutting the tomato peduncle was more compared to cucumber and immature tomato. The reason behind this change is understandable from the cross section view of tomato peduncle. The cross sectional view of mature peduncle shows an onset of secondary growth. Remnants of erstwhile primary xylem can be seen and some secondary tissues have been produced secondary xylem vessels which are composed of tracheids, vessels, xylem fibers and xylem parenchyma. This represents the wood structure of dicot stem that is responsible for giving mechanical support for holding the fruit and upward conduction of tomato stem. The presence of this wood matter inside a mature tomato peduncle is the main cause for increase in cutting force required. The force necessary for cutting the tomato peduncle was obtained as 15.30 kg (150.10 N)

Table 4.21 Force required for cutting tomato peduncle at different stages of harvesting

Harvesting stage of tomato	Force (Kg)
Mature unripe	15.04
Immature unripe	16.64
Mature ripe	16.79

4.3 MATURITY INDICATORS

Evaluation of the biometric properties was also used for determining the maturity of the fruit to be harvested. Maturity criteria are an important factor to be considered while harvesting, because it decides the quality and market value of the product. Maturity indicators indicate the measurements of the maturity of the product. There are several methods to find out the maturity of the fruit like computational method, physical method, physiological method and chemical method. Out of this, physical method is chosen for indicating the maturity of the product.

Usually parameters like size, colour, weight, shape, specific gravity, surface morphology, skin colour, changes in leaves, fruit or flesh firmness, formation of abscission layer, disappearance of calyx etc are considered as the maturity indicators. One simple method used to indicate maturity is skin colour. It is commonly used according to farmer's choice. But scientifically approved colour charts are used for certain crops like tomato as it changes colour. In immature tomato, the colour will be pale green. It changes from pale green to reddish when mature ripe tomatoes are formed. Cucumber does not show much colour variance.

Firmness and flesh changes occurring during the maturity stage is another parameter which indicates maturity. Excess loss of water and moisture from the fruit causes changes in texture of the crop. This can be distinguished by touching the fruit by hand. Also, a sample of fruit from the orchard can be taken and tested in texture analyser for measuring firmness of the fruit.

Formation of abscission layer is another characteristic which indicate maturity. A layer is formed at the peduncle portion as the fruit attains maturity. It was seen both in cucumber and tomato. This is an important icon for determining the maturity of the product.

The simple method used was by analyzing the size and weight of the fruit. It mainly depends upon the market value and requirement of the product and not on physiological factor. Size and weight are considered as poor measures of maturity indication (Sudheer and Indira, 2007). This is because it depends on many factors like cultivars, soil type, climatic condition etc.

Another characteristic that is used to indicate maturity is shape. It may vary depending upon various factors like genetic matter, surface morphology, pest attack etc. This factor does not have much relevance in indicating maturity, as it is dependable on various parameters.

4.4 ADAPTABILITY OF WSN BASED TECHOLOGY FOR HARVESTING

The concept of WSN based harvester for harvesting crops was discussed in 3.1. Introduction of WSN technology to agricultural operations especially in harvesting will help to make the field smart. An ideal harvesting system with WSN based technology should have an ability to detect the maturity of the fruit, recognize the fruit and detaching point, detach the fruit from the parent plant and position the cutting tool at the exact detaching point. The block diagram of a polyhouse with sensors and WSN controls is as shown in figure 4.16.

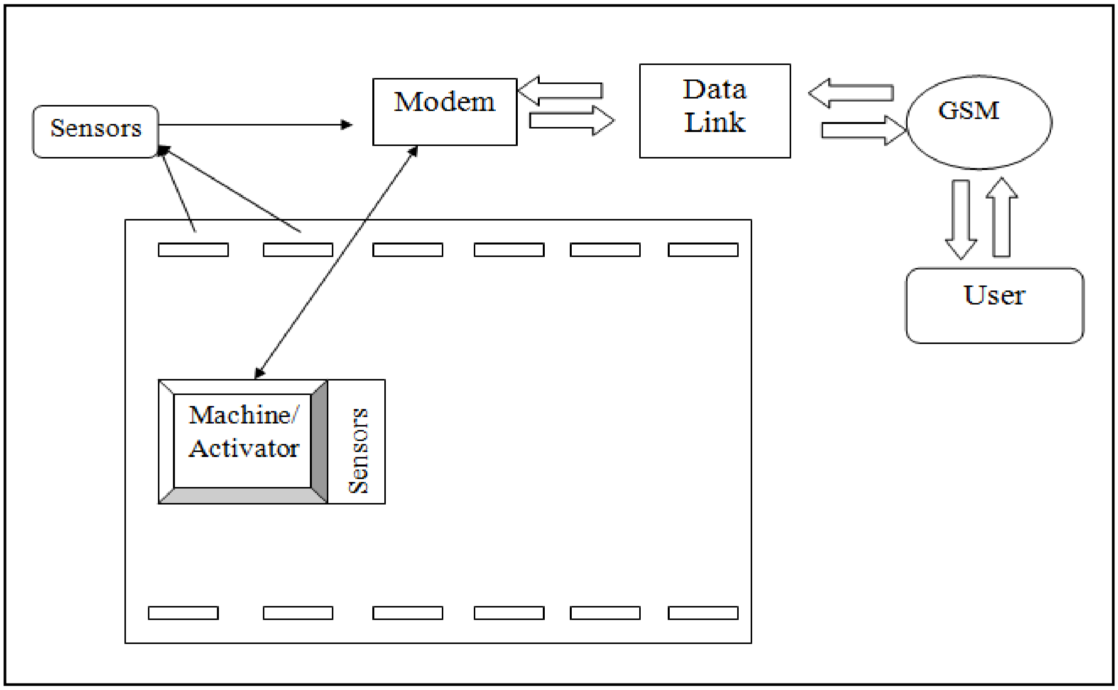


Figure 4.16 Graphical representation of polyhouse with sensors and WSN controls

Advanced harvesting system based on WSN should be able to communicate with the user. The activator and the sensors attached to it make this running. The sensors in the polyhouse sense the fruit and crop condition and it transfers the information to the user through data link. The sensors attached with the activator sense and identify the fruit maturity, position of the fruit and also the exact detaching point. These sensed data are sent to the user and in turn user will give commands. Accordingly, the harvesting machine/activator performs the cutting operation.

The sensing of the biometric properties like colour, size and collision parameters have got much importance in the harvesting operations. Depending upon these parameters, the sensors need to identify the fruit maturity, position of the fruit and cutting point and thus to separate the fruit safely from parent plant and deposit it to a convenient place. The relation between these biometric properties and sensing parameters are give below.

Table 4.22 Relation between biometric properties and sensing parameters

Biometric properties	Sensing parameter		
	Colour	**Size**	**Collision parameter**
Fruit maturity	Influential	Influential	Not Influential
Fruit position	Influential	Influential	Influential
Detaching point	Influential	Not influential	Influential

From all these data, it is clear that maturity of the fruit was dependable on colour in case of tomato since ripe tomato changes its colour from green to red. But cucumber was not able to identify by its colour. Hence it is clear that, with the present facilities it was difficult to identify the fruit maturity with colour change and special recognition systems like imaging algorithms need to be adopted for identifying the maturity of the fruits like cucumber.

Also, it was seen that, the collision parameters were very much high near the cutting zone of the fruit peduncle which makes an unfavorable condition to locate and position the fruit and its detaching point. It also makes it diffiult to detach the fruit from the plant.

So we can ratify that in the present cultivation practice, this technology cannot be used successfully. This can be solved by adopting special plant cultivation methods for crops. This includes tree trellis system and umbrella training system for cucumber and high wire system and high density cultivation for tomato. These special methods will help to reduce the collision parameter and thereby help WSN based harvester to establish in agricultural field.

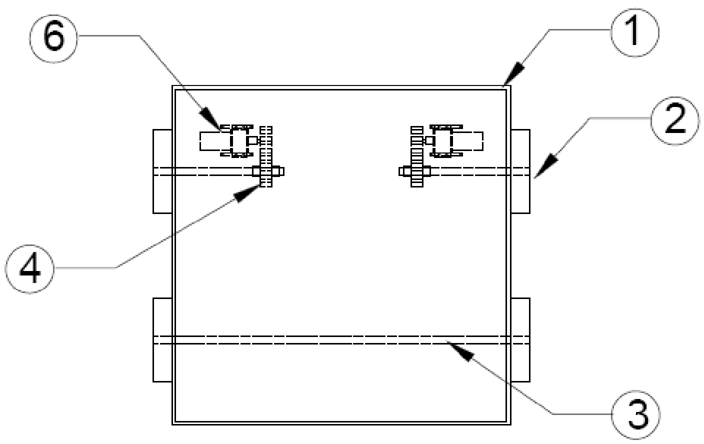
4.5 DESIGN COMPONENTS FOR A REMOTELY OPERATED MECHANICAL HARVESTING SYSTEM SUITABLE FOR WSN BASED TECHNOLOGY

- Moving system
- Positioning system
- Picking system

4.5.1 Moving system

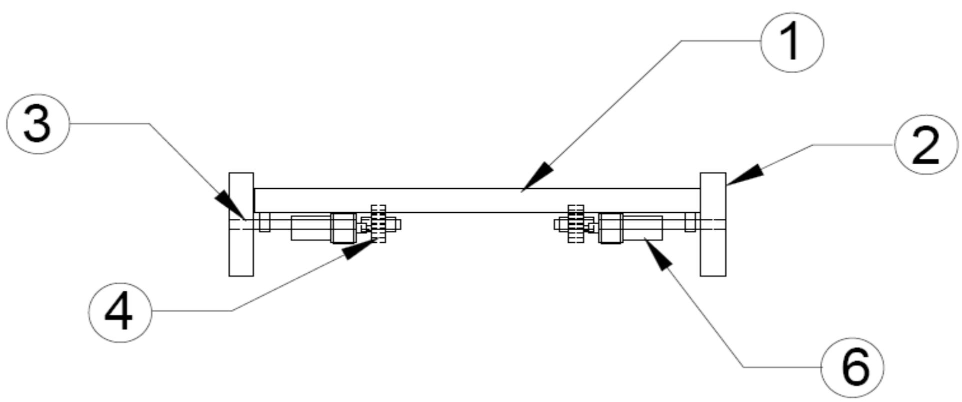
The moving system of a harvester refers to the structure that holds the whole harvesting system. Based on the preliminary studies, a moving system suitable for the harvester was selected and designed.

The platform of the harvester is a tray made of mild steel with a dimension of 45X45 cm. Two pairs of fiber wheels with a diameter of 10 cm are used for motion. The wheels are connected through a shaft. The front wheels are given motion using motor-gear set up. The motor for giving drive is fixed on to the tray and a gear is used to transmit the power to the wheels. This forms the mobile platform of the harvester, which is used to move in between the rows of planting. While turning the base unit, one wheel will be on the inside and the other wheel will be on the outside of the turning arc. So, the outer wheel will have to turn more to cover this greater distance. In order to achieve this, power supply to the inner wheel will be terminated. This comprises the base unit of the harvester. The horizontal and vertical unit of the harvester is mounted on this whole base portion.



No:	Description
1	Tray
2	Wheel
3	Shaft
4	Gear
6	Motor

(a)



(b)

Figure 4.17 (a) Top view and (b) Front view of moving unit

(All dimensions are in cm)

Table 4.23 Specifications of the moving unit

	Minimum	Maximum	Average
Length (mm)	300	600	450
Width (mm)	300	600	450
Capacity of collector (Kg)	1	4	2.5

4.5.2 Position System

Position system consists of a vertical unit which provides up and down motion of cutting tool and a horizontal unit for providing lateral motion of cutting unit.

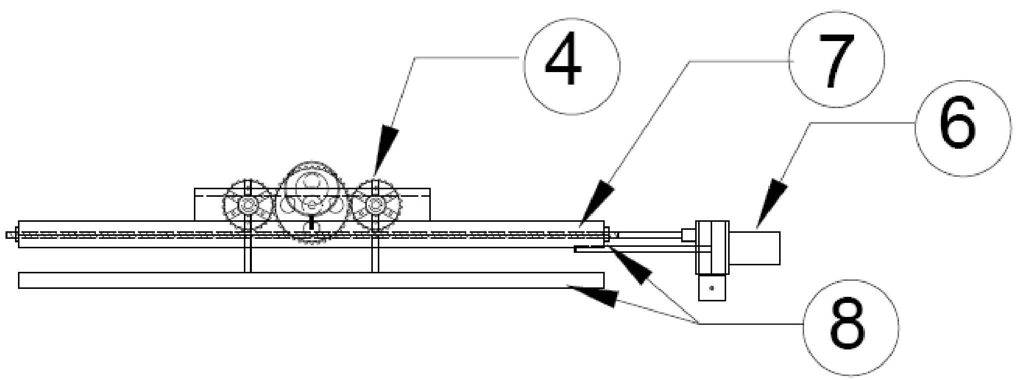
4.5.2.1 Vertical Unit

The vertical unit for longitudinal movement consists of two threaded rod and a square pipe, mounted on the base portion. Mild steel threaded rod with 1 cm diameter is used for this. The height of the vertical unit is 200 cm. A square pipe of 2 cm size is used as a supporting unit. Square pipe and threaded rod is bolted to a mild steel angle (guard) of 18 cm length at top and bottom using lock nut. The bottom side is

Table 4.24 Specifications of the threaded rod

Screw thread	
Outer diameter	10 mm
Inner diameter	8.5 mm
Mean diameter	9 mm
Pitch	1.5 mm

fixed to the base unit through this guard. Motor drive for giving the up and down motion is mounted at the top portion. The motor drive is transmitted to the threaded rods through gears. Big gear with 6 cm diameter is connected to the motor shaft directly. Two small gears with 4 cm diameter are connected to the two threaded rods and are in mesh with the big gear. A cylinder having 10cm length and inside thread is fixed concentric on to the vertical threaded rod and a concentric square pipe is fixed on to the vertical square rod which is free to move up and down. These two threaded cylinders along with the square pipe forms a moving unit. The horizontal unit is bolted to this unit.



No:	Descritption
4	Gear
6	Motor
7	Screw Rod
8	Supporting Unit

Figure 4.18 Top view of vertical unit along with horizontal unit

Table 4.25 Specifications of the gears

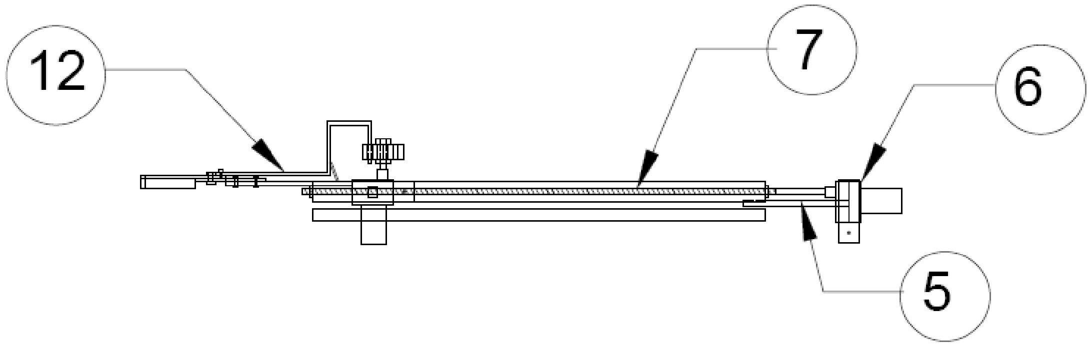
Large gears	
Addendum circle diameter	60.00 mm
Dedendum circle diameter	53.00 mm
Larger width of tooth	2.90 mm
Smaller width of tooth	1.30 mm
Thickness	12.00 mm
Number of teeth	38
Small gears	
Addendum circle diameter	40.00 mm
Dedendum circle diameter	33.00 mm
Larger width of tooth	2.60 mm
Smaller width of tooth	1.20 mm
Thickness	12 .00 mm
Number of teeth	25

4.5.2.2 Horizontal Unit

The horizontal unit for lateral movement consists of a threaded rod, supporting unit, a motor and the cutting unit. A threaded rod of 0.5 cm diameter and 45 cm length is made to pass through the channel. Motor for giving drive is fixed on one end of the threaded rod. Both ends of the rod are locked using a lock nut. The motor shaft is connected directly to the threaded rod and supported using a clamp of 10 cm length, so that the rotary motion of the motor is transferred to the threaded rod. A square rod of length 12 cm extends out from the threaded rod upon which the cutting unit is connected. This gives mechanical support to the cutting unit and also this extension helps to avoid the plant obstacle while harvesting and thus reduces the damages occurring to the plants. Another square rod is connected at an offset of 5 cm below the threaded rod for giving mechanical support to the horizontal unit and holding support to the cutting unit.

Table 4.26 Specifications of the threaded rod

Screw thread	
Outer diameter	6.00 mm
Inner diameter	5.50 mm
Mean diameter	5.75 mm
Pitch	1.00 mm



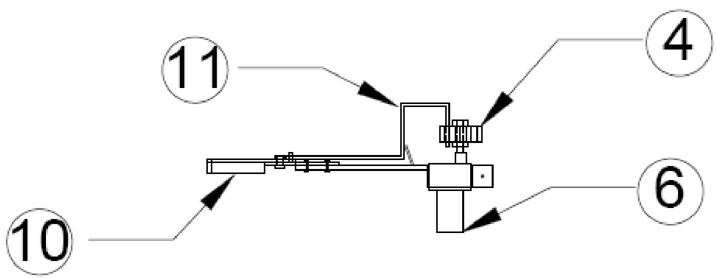
No:	Description
5	Clamp
6	Motor
7	Screw Rod
12	Picking Unit

Figure 4.19 Front view of horizontal unit

4.5.3 Picking System

Picking system is the most crucial part of a harvesting system. This unit collects the fruit, detach it from the parent plant and then deposit it to a convenient place. Many type of cutting systems were used in the mechanical harvesting systems. This includes, cutting unit using gears for grasping and cutting, suction cup with pneumatic system, thermal cutting system, cut and hold mechanisms, hold and cut mechanisms etc. Out of these, cut and hold mechanism was used for the design of the cutting unit. It is the most simple and economical type which was readily available in the local market.

The unit consists of a cutting blade, gripper and a motor. The cutting blade is fixed on a metal piece (guard) of 12 cm length. At one end of the guard, the motor for giving motion is connected. A gear with 4 cm diameter is connected directly to the motor shaft. The motor is clamped firmly to a square rod that extending from the horizontal unit. The gear and the cutting blade are connected using a connecting rod. Both the guard and the extension square rod together resemble an “L” shape on which the whole cutting unit is fixed. The cutting tool is wedge shaped, scissor type, curve blade which has very sharp, thin edge at one side of the blade and thick edge at the other blade. The fiber holding tool just below the cutting blade has grooves for proper holding and has a thickness of 1 cm.



No:	Description
4	Gear
6	Motor
10	Cutting Tool
11	Connecting Rod

Figure 4.20 Front view of Picking Unit

4.5.4 Motor

From analyzing the past works, it was decided to use five motors for achieving motion with three Degrees of Freedom. Two motors were used for providing the rotation of wheels which gave motion of cutting unit in X direction. Another motor was used for giving a Y direction motion and Z direction motion of the cutting unit separately and for the operation of cutting unit, yet another motor was used. From the reviews studied so far, a 12 V DC motor which can produce a torque of 30 Kg.cm and a speed of 300 rpm was selected suitably for the design. The torque developed during the operation of the motor produces mechanical rotation and hence the motion.

Table 4.27 Specifications of the motor

Torque	30 Kg cm
Speed	300 rpm
Voltage supply	12 V
Type	D.C

4.5.5 Control Unit

The control unit adopted for this design is a wired remote control system. It consists of a remote with five pairs of switches for controlling the motion of the motor. The pair of switches with P1, N1 or P2, N2 or P3, N3 or P4, N4 or P5, N5 forms the controlling unit of individual motor.

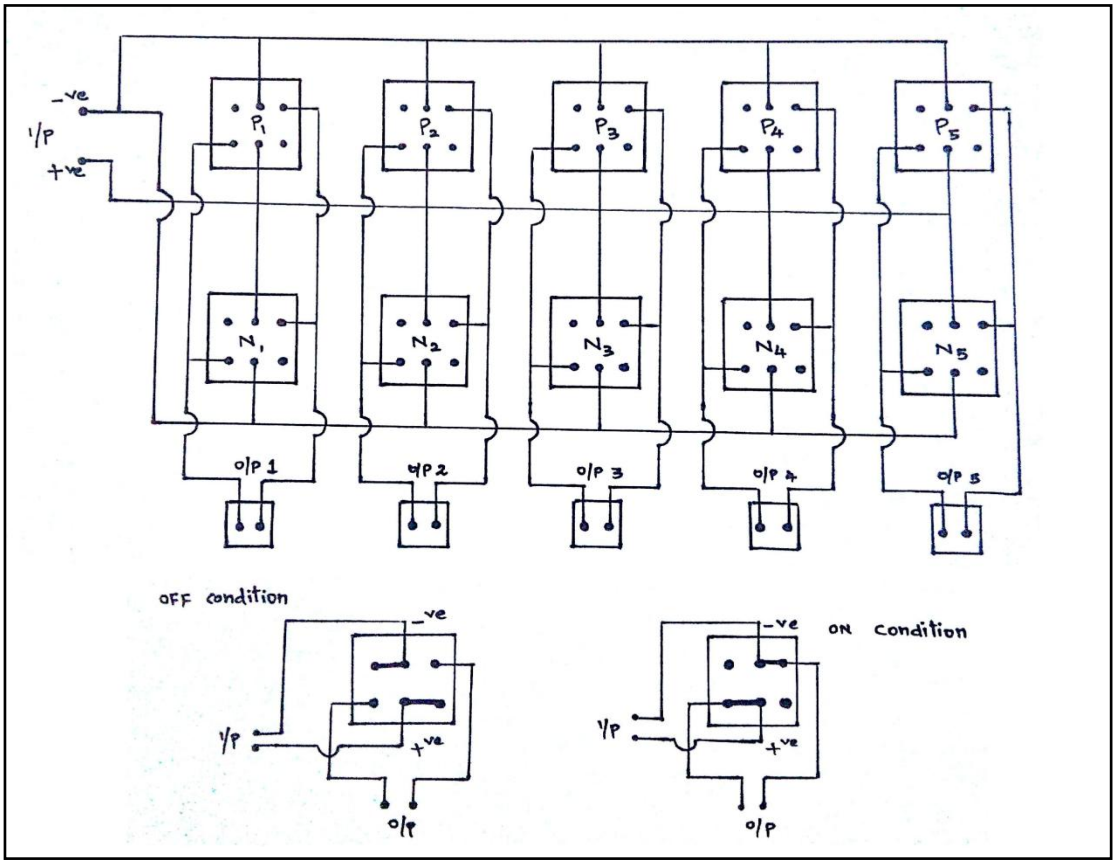


Figure 4. 21 Circuit diagram of Control Board

The switches marked with P1 and P2 gives forward motion of the base unit or the wheels. These two switches need to be operated together in order to get the motion in straight line. While turning the base unit, one wheel will be on the inside and the other wheel will be on the outside of the turning arc. So, the outer wheel will have to turn more to cover this greater distance. In order to achieve this, power supply to the inner wheel will be terminated. Therefore, the switches need to be operated accordingly. The N1 and N2 give motion in reverse direction of the base unit. Similarly, P3 and N3 switches are used to provide motion in upward and downward direction of the cutting unit respectively. P4 and N4 give lateral motion of the cutting unit and P5, N5 operates the motor in cutting unit.

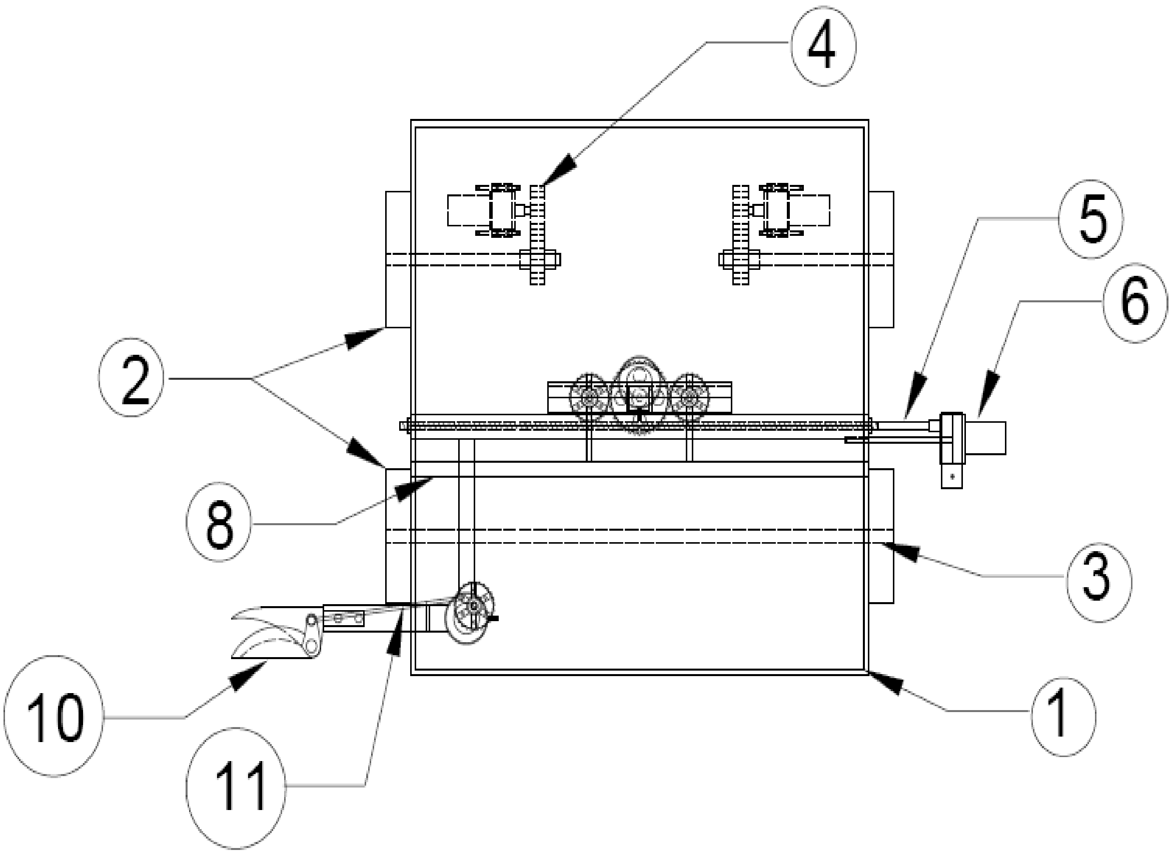
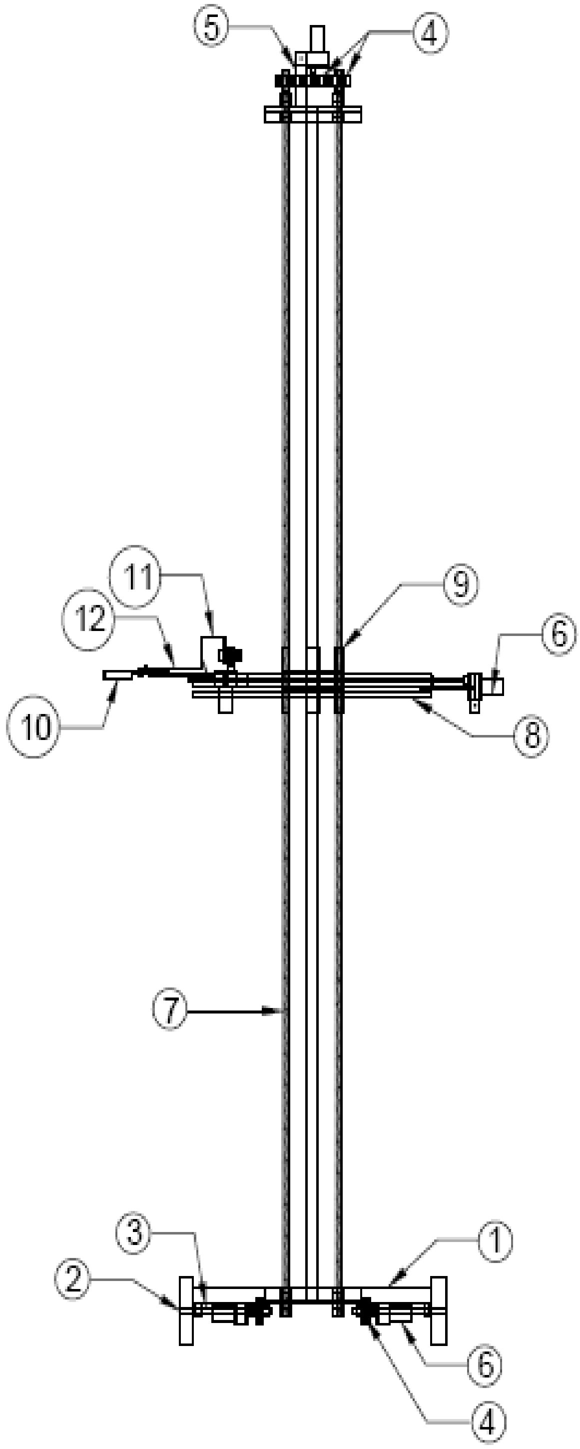


Figure 4.22 Top view of harvester



No:	Description
1	Tray
2	Wheels
3	Shaft
4	Gears
5	Clamp
6	Motor
7	Screw Rod
8	Supporting unit
9	Hexagonal Nut
10	Cutting Tool
11	Connecting Rod
12	Picking Unit

Figure 4.23 Front view of harvester

4.6 LABORATORY PROTOTYPE

The laboratory prototype fabricated based on the design was tested at laboratory set up to check the functionality of its parts. The parts showed a successful functioning in the laboratory environment. The vertical unit and horizontal unit were found operating in smooth condition, but the time taken for the longitudinal and lateral movement was very much great. In order to overcome this issue, it is recommended to use a screw rod of higher pitch value. Also, the cutting unit was working in good condition by holding a weight of around 500 gm without failure.

Summary and Conclusions

Chapter V

SUMMARY AND CONCLUSIONS

Studies on investigations on the adaptability of wireless sensor networks based technologies for harvesting crops were conducted at naturally ventilated polyhouse in the research plot of Precision Farming Development Centre in the instructional farm of KCAET, Tavanur, during February 2016 to May 2016. Based on the evaluation of biometric properties of the crops, a remotely operated harvester was designed for the mechanical harvesting of the crops. The summary of the results obtained from the experiments and the conclusions drawn out from the study are presented in this chapter.

Cucumber and tomato were selected as study samples, since this study mainly focused on polyhouse crops. Hilton variety of cucumber and Anagha variety of tomato were chosen for cultivation. For analyzing the growth pattern of crop, ten cucumber plants and five tomato plants were selected. The main crop growth parameters like height of the plant, number of leaves, leaf length, leaf width, plant circumference, number of fruits, fruit length and fruit circumference were measured. Readings were taken once in a week.

It was observed that, certain parameters affected the design of harvester directly and certain other parameters affected indirectly. Depending upon the height of the plant, the position at which fruits appeared also changes. So, the height of the harvester was decided based on the height of the plant. By considering the heights of both plants, the height of the harvester was fixed at 2 m.

Similarly leaf parameters like number of leaves, leaf length and leaf width affects the performance of the harvester. These parameters have an impact on formation of leaf canopy and leaf density and this in turn contributes to the presence of obstacles in the working area of the machine while in the operation. In this study, since there is no artificial vision system used for identifying the objects, this parameter has a role in identifying and locating the fruit position.

Another parameter that influences the harvesting performance is the plant circumference and collision parameter. The chance of occurrence of damages to the plants and fruits while harvesting depends on these factors. The fruit detaching mechanism will interact directly with the fruit and plant parts. The cutting tool can be designed by considering the circumferential area of the stem in order to reduce the damages occurring while harvesting.

Despite of all the plant parameters, fruit parameters also influence the harvesting operation. The number of uniform sets of fruits on a particular area helps to locate the fruit easily. Along with this, the harvester can work with maximum productivity when the number of fruits in a specified work space is more. The operation of gathering fruits will be less difficult for harvesting equipment that concentrates on individual plant than collective plant operation. This was because, individual plants bear the fruits in a limited area, which makes the number of fruits per working area more.

Apart from all these factors, harvesting was also influenced by the peduncle dimensions of the fruit. The length and firmness of the peduncle will affect the holding performance of the cutting unit. Fruits harvested along with the peduncles have got high market value.

Based on all these biometric properties, a semi autonomous mechanical harvester was developed for harvesting, since the current trend in hi-tech agriculture is switching from manual operation to automatic operations. A harvester with basic components like moving unit, vertical unit and horizontal unit and a cutting unit was designed with three degrees of freedom.

The moving unit adopted for this study was wheel type movable one with forward and reverse movement. It was designed based on the row to row spacing of the plants. It should have the features like stability, capacity to with stand the whole weight of the harvester, free from sinking and load carrying capacity.

The mechanism used for the longitudinal and lateral movement of the harvester was linear actuators. It gives a straight line motion using a circular motion of an electric motor. Actuator used for this study is mechanical actuators. Mechanical actuator works on the principle of conversion of rotary motion of a motor to linear motion. The conversion was done via simple mechanism like screw type. The rotation of the electric motor is mechanically connected to rotate a threaded rod or screw using a gear. The rod has continuous helical thread with definite pitch. A nut having corresponding helical threads is threaded onto the rod. The nut is prevented from rotating freely with the rod, since it gets interlocked with the non rotating part of the actuator. Therefore when the rod is rotated using the motor, the nut will be driven along the threads. Depending upon the direction of the rotation of the rod or the screw, the direction of motion of nut can be determined. This motion of nut can be converted to usable linear motion by connecting through necessary linkages to the nut. This mechanism was used for both longitudinal and lateral movements.

A cut and hold mechanism was used for the cutting unit. Cutting tool which was available in the local market was chosen for the design with wedge shaped cutting blade of blade thickness 1.63 mm and wedge angle of 12^0. A gripper made of fiber with a width of 1cm was used as the holder to hold the fruit without slipping.

The harvester designed is a preliminary prototype which needs further modification and improvements. And based on the design, a laboratory prototype was fabricated and its functionality was tested.

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Appendices

Appendix I

Specifications of the polyhouse

Particulars	Specifications
Polyhouse height(center)	4 m
Polyhouse height (side)	2.5 m
Area inside	45.08 m^2
GI pipe posts	0.05 m diameter
Roofing	200 micron thickness UV stabilized LDPE

Appendix II

List of materials: Moving Unit

Sl. No:	Parts	Notation	Specification	Number of items
1.	Tray	BU-01	45x45 cm	1
2.	Wheel	BU-02	Size-Ø 10 cm Width- 2.5 cm	4
3.	Shaft	BU-03	Size-Ø 1.5 cm Length-47.5 cm	3
4.	Gear	BU-04	Size-Ø4 cm Thickness-1.2 cm	4
5.	Motor	BU-05	Rpm-300 Volt-12 V	2
6.	Clamp	BU-06	Suitable for motor	1

Appendix III

List of materials: Vertical Unit

Sl. No:	Parts	Notation	Specifications	Number of items
1.	Screw rod	VU-01	Size- M10 Length-200 cm	2
2.	Supporting unit	VU-02	Size-2 cm &Length-200 cm(square rod)	1
			Size-2.5 cm & length-1.8 cm (guard)	2
3.	Hexagonal nut	VU-03	Size-M10	24
4.	Moving unit	VU-04	Length -10 cm Size- M10 (cylinder) Size-2 cm(square pipe)	3
5.	Gear-small	VU-05	Size- Ø4 cm Thickness-1.2	2
6.	Gear- big	VU-06	Size- Ø6 cm Thickness-1.2 cm	1
7.	Bolt	VU-07	Size-M10	4
8.	Motor	VU-08	Rpm-300 Volt-12 V	1
9.	Clamp	VU-09	Suitable for motor	1

Appendix IV

List of materials: Horizontal Unit

Sl. No:	Parts	Notation	Specifications	Number of items
1.	Screw rod	HU-01	Size- Ø5 Length-47 cm	1
2.	Motor	HU-02	Rpm-300 Volt-12 V	1
3.	Hexagonal nut	HU-03	Size- Ø5	6
4.	Supporting unit	HU-04	Size- 2cm& length-45 cm (Square channel)	1
			Size-1.2 cm &Length-45 cm (square rod)	1
			Size-0.5cm&length-4.5 cm (square rod)	2
5.	Clamp	HU-05	Suitable for motor	1

Appendix V

List of materials: Picking Unit

Sl. No:	Parts	Notation	Specifications	Number of items
1.	Cutting tool	CU-01	Length-5.4 cm Width-1.3 cm Wedge angle- 12^0	1
2.	Connecting rod	CU-02	Length-15.5 cm Size- Ø0.3 cm	1
3.	Motor	CU-03	Rpm-300 Volt-12 V	1
4.	Gear	CU-04	Size- Ø4 cm Thickness-1.2	1
5.	Supporting unit	CU-05	Size-1.5 cm & length-12.5 cm(square rod)	1
			Length-12.5 cm & width-2 cm(guard)	1
6.	Clamp	CU-06	Suitable for motor	1

INVESTIGATIONS ON THE ADPTABILITY OF WIRELESS SENSOR NETWORKS (WSN) BASED TECHNOLOGY FOR HARVESTING CROPS

By

AYISHA MANGAT

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ABSTRACT

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Abstract

Harvesting has been identified as one of the critical and resource consuming operation because of several reasons especially inside polyhouse structures. Knowledge of physical properties of crops and fruits like cucumber plays an important role in the design and optimization of its machinery. Evaluation of these properties like plant height, leaf numbers, leaf length, leaf width, fruit length and width were taken for observation. It was seen that, these properties had a direct impact on deciding the components of the harvester. Plant height determined the height of the harvester; leaf parameters decided the obstacle parameters in the work space. Fruit holding capacity of the cutting unit was depended on fruit parameters. By analyzing all these data and the past work in the field of robotics, a preliminary model of a harvester was fabricated. Out of the harvesters developed so far in the field of agriculture, the most simple and economical method was selected for this study. The principle of linear actuators was adapted for the design of the harvester by incorporating screw rods and DC motors. The basic components for the harvester were identified with three Degrees of Freedom. The moving unit with wheels contributes to the motion in X direction. The vertical screw thread makes the movement in Y direction and the horizontal unit gives the motion in Z direction. By studying the biometric properties of plants and crops, the height of the harvester was confined to 2 m, width of horizontal unit as 45 cm and the base platform with 45X45 cm. A control board was used for controlling the motors which causes motion for the threaded rods. Accordingly, a laboratory model was fabricated and its functionality was tested. It was found working successfully in the laboratory conditions.

The current trend in high-tech agriculture is towards switching from a manual system to automatic operations. Hence, the present study is a promising technology that can be converted to a fully automatic machine with future developments.