# AUTONOMOUS WEEDING MOBILE ROBOT

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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# ABSTRACT

Autonomous mobile robots are being used in various fields to replace manual labor and increase efficiency. The world is witnessing an increasing application of autonomous devices in agriculture as well, but this technology is yet to make inroads in Pakistani farmlands. Pakistan lags behind the world in agricultural yields per unit area due to outdated farming methods. Along with other agricultural practices, weed control methods employed in Pakistani farmlands are not only inefficient and time consuming but also pose a threat to the environment. Autonomous robots are being used in farms around the world as they provide higher precision in weeding and greater time efficiency. Instead of using harmful herbicides, robots equipped with laser actuators are being adopted as a sustainable alternative. Unfortunately, the cost of these robots is beyond the purchasing power of Pakistani farmers. The only way to ensure penetration of this technology in Pakistani farmlands is to make it affordable. This project focuses on the fabrication of an autonomous laser weeding robot that can automate weeding procedure, replace harmful herbicides and boost yield per unit area. The focus of the project is to develop an affordable functioning robot that achieves the global benchmarks for the efficiency of weeding robots. The robot is manufactured using indigenous material and machining processes which helped greatly in reducing the cost of production.

# ACKNOWLEDGMENTS

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## ORIGINALITY REPORT

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# ABBREVIATIONS

| | |
|---|---|
| RGB | Red, Green, Blue color model |
| HSV | Hue, Saturation, Value Color Model |
| ROS | Robot Operating System |
| OpenCV | Open Computer Vision Library |

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Field robots are autonomous or teleoperated vehicles designed and programmed to function in unstructured outdoor environments. They are built to navigate harsh dynamic surroundings where human access may be limited and automate laborious tasks. Subclassifications of field robots include aerial drones, ground-based and underwater robots. Based on the method of mobility, ground-based robots are further classified as either wheeled, tracked or legged robots.

Wheeled field robots are equipped with wheels and sensors for locomotion and programmed with different algorithms to perform tasks without human intervention. The sensors include encoders, camera, ultrasonic sensors, Lidar etc which are integrated with the chassis using a microcontroller for path planning and navigation in outdoor environments. It enables them to be used in a multitude of applications such as scouting, agriculture, space exploration, disaster management and more.

Agriculture is one sector where field robots excel the most due to their ability of navigating rough terrains and performing labor intensive tasks timely and effectively. With the trend of precision farming increasing across the globe, agriculture robots can monitor crop and soil parameters and efficiently use the resources. Moreover, they have the potential to play a vital role in improving soil health and reducing the environmental impact of farming. And above all, due to automated farming, crop yield and quality is increased manifold. Seeding, planting, crop monitoring, weed and pesticide control, selective harvesting, tilling, and irrigation are some of the farming works that can be automated by agriculture robots.

Weeding is the process of removing unwanted plants from the cultivated crops. Weeds not only compete with crops for nutrients and resources, but also adversely affect quality and yield. Traditionally, weeds are removed either by manual method such pulling and hoeing or by use of special chemicals such as herbicides. However, manual methods have very little productivity and use of herbicides destroys the soil ecosystem. Furthermore, the number of herbicide resistant weeds is also on the rise [1]. Though automated weed removal methods have been developed based on mobile robots and drones by utilizing the above-mentioned strategies using, there is still need for more innovative technologies to make weeding, one of the most essential agriculture practices, efficient and sustainable.

Pakistan's Agriculture industry, despite being a major contributor to the GDP with more than 20% share and employing almost half of the labor force directly and indirectly [2], has failed to achieve its true potential due the outdated methods still in practice today. Ineffective weed control is a considerable factor since the average yield loss due to weeds in Pakistan is estimated at 11.5% [3]. Automated weed removal can not only help increase yields and drive the economy and exports, but also provide time and cost benefits to the local farmers. In light of this, the aim of our project is to design, locally fabricate and program an autonomous weeding robot offering the farmers a feasible solution and fulfilling United Nation's SDG No.2 of promoting sustainable agriculture.

## 1.2 Problem Statement

Ineffective manual methods of weed removal in agriculture across Pakistan result in poor yields. To keep pace with the world shifting towards precision farming, it is essential to develop sustainable autonomous vehicles capable of effective weeding. The following problem statement describe the aims of the project

"Design, manufacturing, and programming of autonomous weeding robot with three axis laser actuation mechanism and weed detection for automated and sustainable weed removal in agriculture"

## 1.3 Objectives

The six-wheeled mobile robot aims at achieving the following objectives to comprehensively address the identified problem pertaining to ineffective weeding:

1. Efficient real-time weed detection and actuation.
2. Autonomous navigation and motion planning.
3. Mechanical stability during motion on rugged terrain

## 1.4 Summary of Work

To ensure the development of an effective working model, the project got underway with consideration of all the objects and KPIs. Every component of the project was dependent on the chassis and suspension system, which was its main component. As a result, the project began by selecting an efficient and affordable mechanism to guarantee the drive's stability and smoothness in order to have an effective image recognition phenomenon. The model was designed in Solidworks in compliance with the required dynamics and desired dimensions after choosing the double crank mechanism suspension system. Following numerous iterations, the modeling phase was completed, and the simulation phase followed, during which the behavior of the suspension system and chassis was evaluated under conditions of maximum load.

After finishing all of the designing and simulating, the robot was moved to production phase. Manufacturing of chassis and suspension systems began. After all individual parts had been manufactured, we moved on to the assembly phase, where all mechanical components and mechanisms were put together to create a single unit robot.

After being mounted on the chassis, all of the circuitry was assembled, tested, and then brought to team controls so that the circuitry installed could be programmed with the necessary codes and programs.

## 1.5 Scope

This project addresses local farmlands in completely automating the weed remove process from the crop. It will also replace herbicide usage in the crop, which negatively impacts the soil and the environment. Therefore, it aims to achieve a solution which is economically, environment friendly, less labor intensive, precise and time saving. To achieve complete on field automation, a few related technologies are required including a charging station and a pickup and dropping mechanism for the robot from the field. However, this project is only concerned with weed detection using computer vision and weeding using motor actuated laser mechanism built using locally available resources to keep the development costs low. For the prototype, this project assumes that the maximum height of the crop would be less than 150mm, and the crops would be planted in a straight line for row detection which can be followed by the robot for navigation.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Weeding is a centuries old practice that has been employed to minimize the competition for nutrients among the crop and unnecessary herbs. The methods of weeding have evolved greatly over time. Earliest weeding methodology involved the manual plucking of weeds.

Figure 1 Manual Weeding

This approach was immensely tedious and time consuming. Weeding of large farmlands required substantial manpower that incurred a significant cost as well. Manual weeding has also been found to cause permanent back injuries [4].

### 2.1.1 Mechanical Weeding

In the latter half of the twentieth century, mechanical weeding practices found prevalence. Mechanical methods serve as a useful replacement for manual labor and provided time efficiency, but they have their own share of demerits. The foremost demerit being the lack of ability of a mechanical weeder to operate closer to the crop [5].

Harrows, hoes and similar bladed actuators are attached to a locomotive to eliminate weeds mechanically. These actuators can pose a risk to the crop itself if operated closer to the plantation. The second important limitation is the chance of the weed survival even after being disturbed by mechanically. As the weeders do not have in place any precision mechanism, it is not possible to ensure that the damage incurred upon the weeds would be fatal. The survival rate of mechanically uprooted weeds has been reported to be as high as 45% [6].

Figure 2 Mechanical Weeding

### 2.1.2 Use of Herbicides

Another method of weed removal is the use of herbicides. This practice is incumbent in most of the farmlands in Pakistan. Herbicides are diluted in water and applied by spraying over the farmland.

Figure 3 Herbicide Spray for Weed Control

They were initially found to be effective against weed control but maintaining efficacy is now becoming a challenge for the herbicide manufacturers as more and more herbicide-resistant weed species are being reported. This defiance against herbicides is only expected to increase with time. In addition to the rising inefficacy of herbicides, their usage poses a sustainability threat as well. These chemicals are prone to end up in sources of fresh water when sprayed on the crop. They are carried by rainwater into water reservoirs, or they leach into the soil to pollute groundwater. A large proportion of them also ends up in harvested produce. Human beings are always at a risk of consuming these harmful chemicals [1]**.**

### 2.1.3 Use of Robotics in Weeding

With application of field robotics, automation and precision farming can be ensured in weeding methods. Agricultural robots have been area of interest for many researchers as well as manufacturers of late. These robots vary in the design of their chassis, suspension mechanism, power source, control systems, weed detection methods and weed control actuation mechanism. A stable chassis and an effective suspension system are necessary requisites for any agricultural robot to deliver.

### 2.1.4 Laser Weeding

Regarding the choice of actuators, we are aware of the threat that herbicides pose to the environment and the limitations associated with the use of mechanical tools. A sustainable alternative that has the potential to achieve desired results is a laser actuator. It does not contaminate the edibles and fresh water sources. It can also be used in close proximity to the crop without causing any damage to the plantation.

In comparison with the mechanical weeders, it also offers a significant advantage in terms of power requirements. A laser actuator is only activated upon the detection of weed. It does not draw current continuously acting as a perpetual power sink. On the other hand, in absence of any weed detection methodology, mechanical actuators require continuous power supply to run through the soil as the robot moves across the field [7]. Precision weeding via laser can decrease the energy input by 10–90% [8]. The extent of damage depends on multiple factors including on weed species, laser spot position, growth size, laser spot area, and applied laser energy [9]. Laser burns the weed by applying concentrated energy. This heating effect is limited to a very small area. The risk of harming the soil and crop in the vicinity of the weed is greatly reduced [10].

Figure 4 Laser Weeding

The following section discusses in detail the academic literature pertaining to the design, actuation, navigation and requisite processes and components for a laser weeding robot.

## 2.2 Related Works

### 2.2.1 Methods of Weed Removal

A solar powered robot designed to spot and eliminate weed was developed equipped with cameras that will detect the weed which will then be processed by the computer system. The computer system will then spray a small dose of herbicide using a sprayer powered by the solar power system and batteries [11]. Another way to eliminate weed is to equip a robot with sensors and small scissors. These scissors are effective but a lot more time consuming than other methods. However, both these methods are expensive therefore they are not suitable for small or medium scale farmlands [12].

### 2.2.2 Navigation for Agri Robots

Precise navigation of mobile robots in complicated agricultural environment is a necessity for automating different tasks. Vision-based path planning techniques currently being researched for agriculture robots include mapping, SLAM, row following etc. There exist many methods for obtaining a map of the field but minor changes in the environment can cause changes on the map structure or shape in actual agricultural operation. Simultaneous localization and mapping (SLAM) provides an alternate solution, but for larger and more complex environments, the time complexity and space complexity of data processing is extremely increased, thereby adversely affecting the efficiency of this approach [13]. Other intelligent vision-based navigation methods include the use of monocular vision to extract depth information from 2D images and stereo vision system using two cameras to capture images from different perspectives and extract depth information with greater accuracy [14]. However, such a vision system is more complex and expensive.

A new simpler approach is to apply a series of image processing techniques and find the inter-row space between the crops and then calculate the current pose and orientation with the help of Hough transform [15]. Such method enables the robot to independent locate the row of crop and follow it without the need of complex vision and mapping techniques. For high weed density environment, the method can be improved by applying appropriate color feature model to separate the crop from surrounding, filtering the noise produced by weed by eliminating small-area contours and finally extracting the navigation path through Hough transformation [16].

### 2.3 Requisite Processes and Components

The development of a practical solution to automate weeding process in agriculture requires research in many disciplines such as mobile robots, actuating systems, electronics, path planning and computer vision. Implementation of path planning techniques based on computer vision and image processing for crop and weed detection is the key factor towards independent navigation and weed removal. Moreover, in order to integrate these techniques with the physical structure, knowledge of working of different sensor and microcontrollers is essential.

### 2.3.1 Path Planning

Path planning for agricultural robots includes the implementation of algorithms that allow the robot to move across a farm or field and execute different activities. The aim is to create a path that reduces the time it takes the robot to perform its function while avoiding obstacles, keeping within the field limits, and taking into consideration the specific characteristic of the crops being cultivated [17]. Path planning can either be global, where the robot's position itself and the goal position are known in a constructed map, or local based on changing environment, robot's own state estimation and creating a collision free path. Path planning for agriculture robots includes further process such as

#### *2.3.1.1 Localization*

For agriculture robots, localization is particularly important for the robot to know its own position relative to the field and the crops. Localization is further classified as either absolute localization where robots absolute's position is determined using landmarks and signals or relative localization where position is determined using onboard sensors such as encoders. GPS based absolute localization is commonly used for field robots but does not provide higher accuracy required for agriculture applications and signals can be can affected by environmental factors. Visual localization is an alternate technique where images from onboard cameras are processed and interpreted to obtain the position. Relative localization can be performed by dead reckoning using motor encoders to calculate the distance and direction travelled based on rotation of the wheels, known as odometry. For the weeding robot, visual localization and odometry are effective tools of absolute and relative localization respectively.

#### *2.3.1.2 Mapping*

The use of sensors and mapping technology to produce a map of the field and the crops within it is an important aspect of path planning for agriculture robots. This map may then be used to determine an effective course for the robot, taking into consideration the size and structure of the field, the position of obstacles like rocks or trees, and the location and growth stage of the crops [17]. Mapping can be lidar or camera based. However, based on the functionality of the robot, mapping may not provide an effective navigation solution due diverse and dynamic agriculture environment with growing crops. Furthermore, the higher cost and programming complexity associated with mapping techniques call for relatively simple solutions such as crop row following.

#### *2.3.1.3 Crop Row Following*

It is the robot's ability to detect and follow the contours of crop rows or other features in the field. By doing so, it can perform both in-row and intra-row weeding while following lines of crops row. At the end of each row, the robot performs a turn and enters the next row and this process is continued. By doing so, the robot can avoid the chassis and wheels from coming in contact with the crops and damaging them. Computer vision based implementation of row following is best suited where crops rows are detected by image processing techniques such as Hough transforms, and robot wheel motors are controlled to follow them [18].

### 2.3.2 Image Processing

Image processing is one of the main pillars for the working of the autonomous weeding robot. It is not only a necessary components of path planning where crops rows are detected and followed, but also for differentiating weed and crops. It involves obtaining a video stream from cameras at calibrated height and distance, then segmenting the image based on working area and region of interest. The image is preprocessed by converting from RGB spectrum to HSV and different techniques such as dilation, erosion, blur etc are applied. Feature extraction is carried out by identifying visual features such as color and size. Then different parameters are used to classify the objects as either crop or weed [19]. Weed mapping is the final step where all the detected weeds are located in terms of pixels which are converted to distances for the laser motion. All these functions can be implemented using the OpenCV library in C++ for higher run time.

### 2.3.3 Components

One of the prime objectives of this project is to deliver a sustainable yet economical solution to modern weeding problems. Keeping that in mind, all of the components were sourced locally with a few of them 3D printed. The following components were used in the Autonomous Weeding Robot:

*2.3.3.1 Raspberry Pi 3B:*

The Raspberry Pi is a low cost, energy efficient, credit-card sized computer which can run few operating systems, including Ubuntu and Windows 10 [20]. These portable machine vision and robotics applications are clearly suited for this compact, ubiquitous platform's high performance. All the image processing and computation would take place from the Raspberry Pi. Since the project requires real time image processing capabilities while controlling the entire robot, it is a suitable fit considering it will be receiving inputs from the two Arduinos which will consequently control the robot.

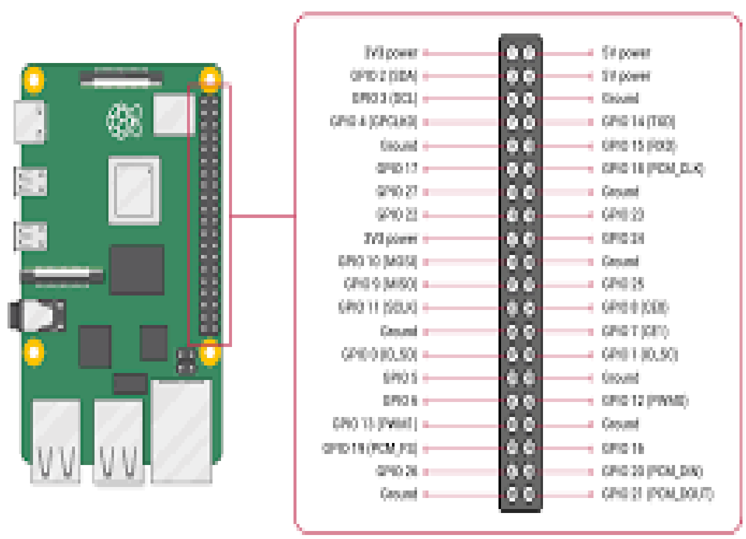

Figure 5 Raspberry Pi 3B Layout

*2.3.3.2 Arduino UNO:*

Arduinos are microcontrollers-based devices that can be used to build digital systems [21]. The Arduino Uno Control Interface (AUCI) is a microcontroller board based on the ATmega328P (datasheet) and has 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header, and a reset button. It also has 14 digital input/output pins, of which 6 can be used as PWM outputs.

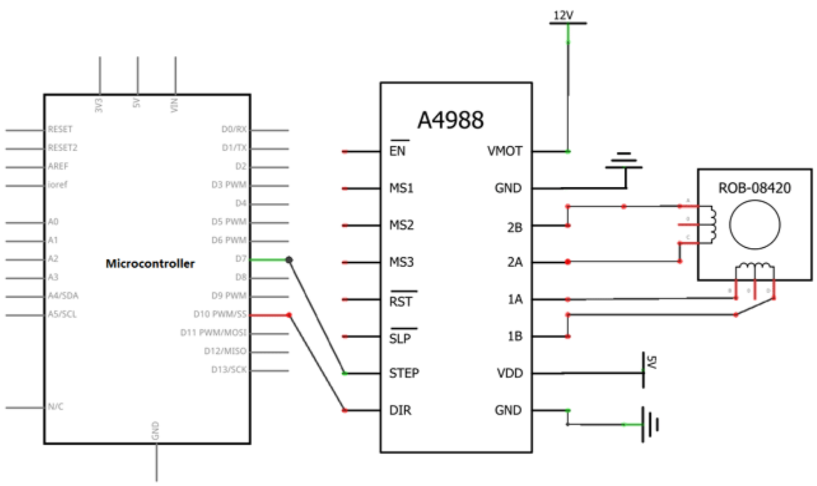


Figure 6 Arduino Uno Layout

*2.3.3.3 CNC Shield:*

The CNC shield is an electronic hardware module used to control 4 stepper motors at a time. The module is capable of driving 4 separate stepper motors and 3 sensors. 4 A4988 motor controllers are connected to the shield via pins while the shield itself is mounted on the Arduino. The shield is equipped with a set of capacitors to protect the entire circuit. The shield is specifically designed to be mounted on an Arduino UNO. The shield also supports micro-stepping of up to 1/32.

- Maximum Output Current: 3.6A (each motor)
- Logic Input Voltage: 3.3 to 5V
- Input Supply and Output Motor Voltage: 12 to 36V

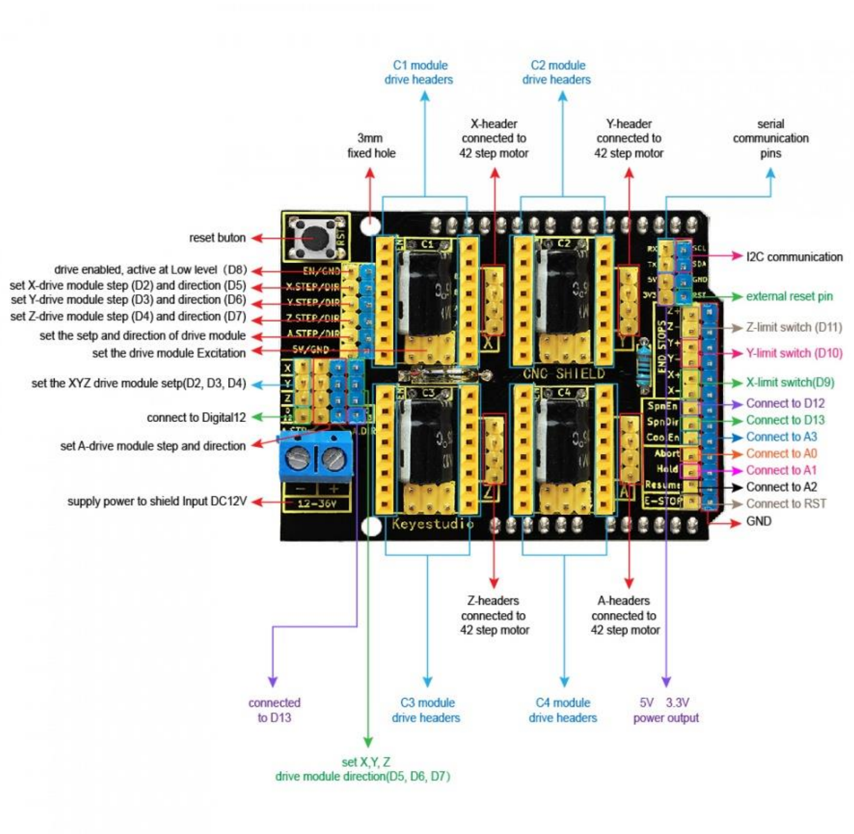


Figure 7: CNC Shield Layout

*2.3.3.3 A4988 Motor Controller:*

The A4988 is a motor controller that can drive bipolar stepper motors with up to 2A per phase. It has a built-in translator that allows it to operate with just two control inputs. The A4988 are specifically sued for stepper motors at it supports up to 16 micro steps per full step, which increases the resolution and smoothness of the motor movement.

- Load Supply Current: 35V
- Output Current: 2A
- Logic Input Voltage: 0.3 to 5V
- Output Motor Voltage: 2 to 37V

*2.3.3.4 IR Sensor:*

An electrical device known as an infrared proximity sensor, sometimes known as an IR sensor, emits infrared light to sense some feature of its surroundings and can be used to detect an object's movements. This passive sensor can only measure infrared radiation because it is passive.

*2.3.3.5 Battery Controller:*

A battery controller is used to protect the entire circuit and the batteries from overheating and damaging the circuit. The controller also has the ability to act as a charger for the battery cells as well. The battery controller maintains a 3A current with 12V during charging to ensure prolonged battery life and prevent any accidents.

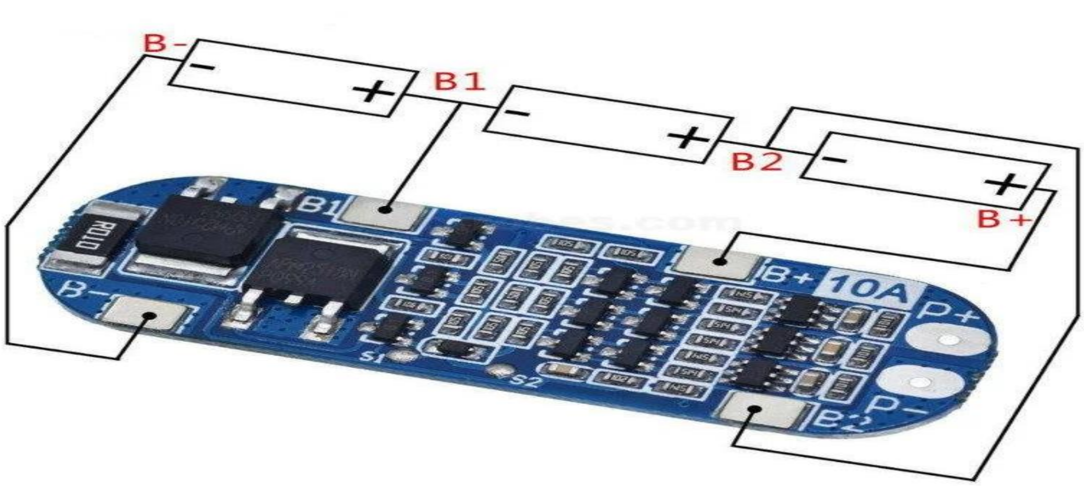


Figure 8 Battery Management System (BMS) for Battery Charging

*2.3.3.6 Pi Cam:*

For use with the Raspberry Pi single-board computer, the Pi camera is a camera module. It is a little, inexpensive camera that is simple to combine with the Raspberry Pi in order to take pictures and videos.

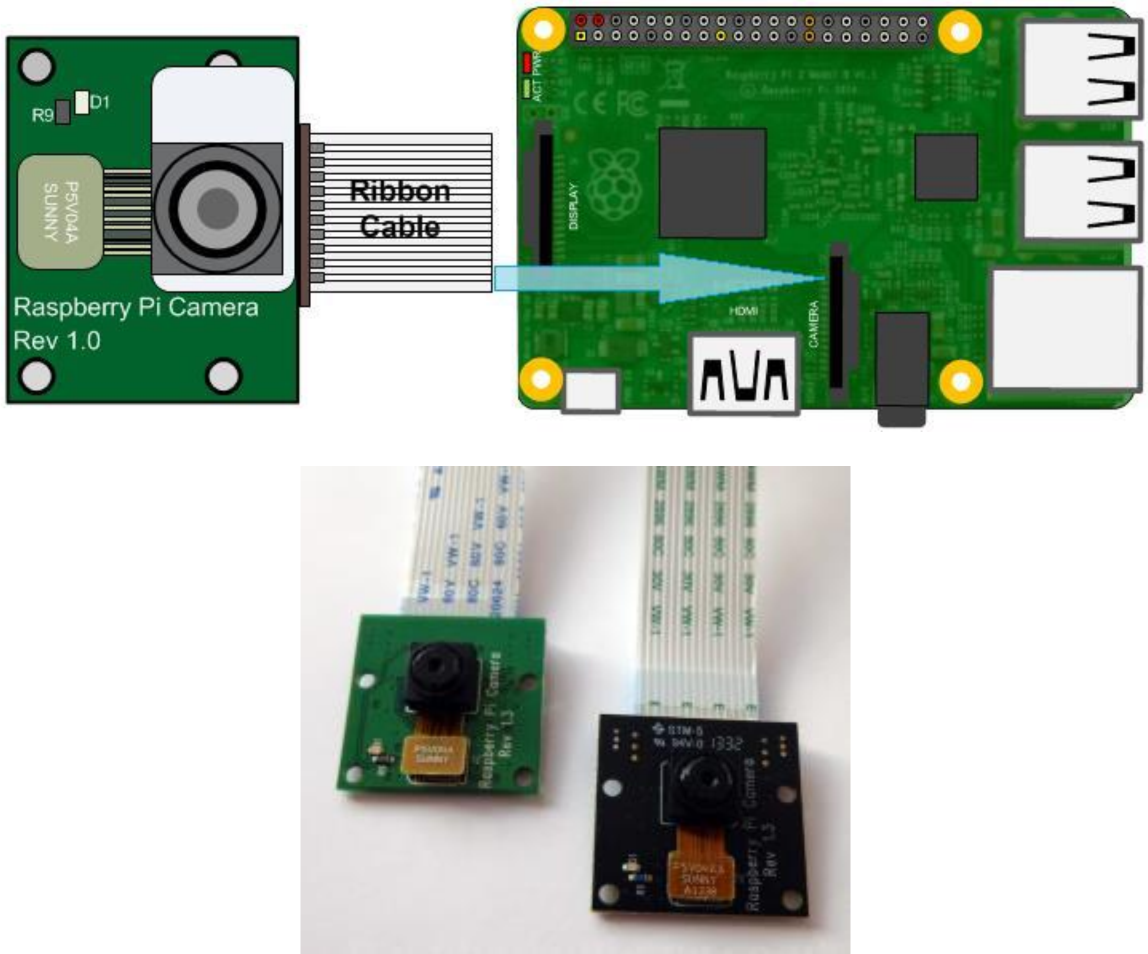


Figure 9 Pi Cam and Connection with Raspberry Pi

## 2.4 Conclusion

The existing academic literature regarding the autonomous weeding robots underlines the core requisites for any such robot to function effectively. The required characteristics for the chassis and suspension mechanism of an agricultural robot were highlighted. The stable locomotion on farmlands requires an irrepressible chassis and a durable suspension. The cost of contemporary agricultural robots is beyond the purchasing power of Pakistani farmers because the chassis is constructed with huge material reinforcements to provide required stability. This adds to the cost of the weeder. We identified that there is a need to minimize the cost of manufacturing of chassis and suspension system by optimizing the design instead of adding abundant material.

The pre-existing work related to path planning, localization, mapping and image processing in autonomous robots provides us a good foundation to approach the project. The merits and demerits of multiple contemporary methodologies and the particular challenges in operating autonomous robots in Pakistani farmlands were considered before devising our approach.

Different weed control actuating mechanisms were studied and evaluated based on their effectiveness, cost and environmental fall out. The required components for the fabrication and installation of the laser actuation mechanism were identified.

# CHAPTER 3: METHODOLOGY

## 3.1 Project Overview

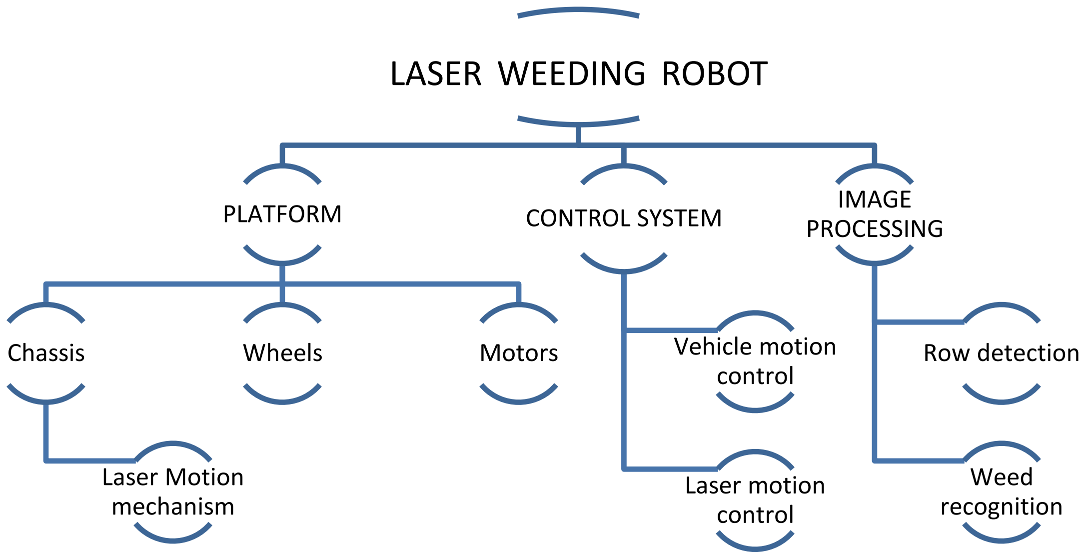


Figure 10 Project Overview Layout

A six wheeled robot is designed with 4 driver wheels. The frame has 760 mm length and 406mm width. The height of the frame from the ground is 321mm. All the links are made of stainless steel while the brackets are composed of mild steel. The selection of material was done keeping in mind the yield and shear strength, and the machinability of the material. Pin joints are used where 1 degree of freedom of motion was required. Pin joints, as well, are made of stainless steel. Immovable joints were executed via bench fitting. Stepper motors are used to drive the wheels.

The laser actuation mechanism is fabricated using a belt-pulley mechanism and a power screw. Belt-pulley mechanism provides motion two axes, and the power screw moves the third axis. A common application of this mechanism is in 3D printing and CNC machining [22]. Four stepper motors are used for movement of laser in all 3 axes. Smooth rods are used to support the laser. The mechanism is powered by lithium-ion batteries. The laser motion is controlled by Arduino.

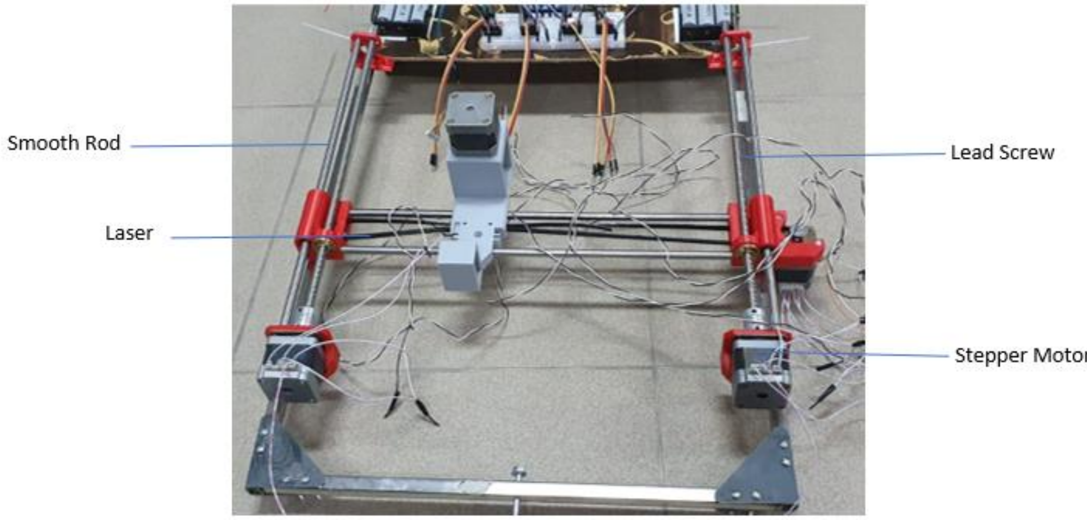


Figure 11 Three Axis Laser Actuation Mechanism

Two cameras are used in this robot assembly. One camera faces the ground and is used to detect weeds while the other camera is used to detect the rows of the crop. The robot follows the crop rows in its autonomous motion. As soon as the ground-facing camera detects a weed, the robot motion is halted. This is done by stopping the motors attached to the wheels. The exact coordinates of the weed in plane are extracted and the Arduino moves the laser along two axes to be placed perpendicularly above the weed. Once the laser is perpendicularly above the weed, the laser is lowered using the same belt-pulley mechanism as described above. This movement in the z-axis is performed to lower the distance between the laser and the weed to ensure maximum damage and minimize chances of regrowth of weed.

The electronics components namely Raspberry Pi 3B, Arduino UNO, lithium-ion batteries, motor controller, battery controller and bread boards are mounted on a wooden platform on the robot.

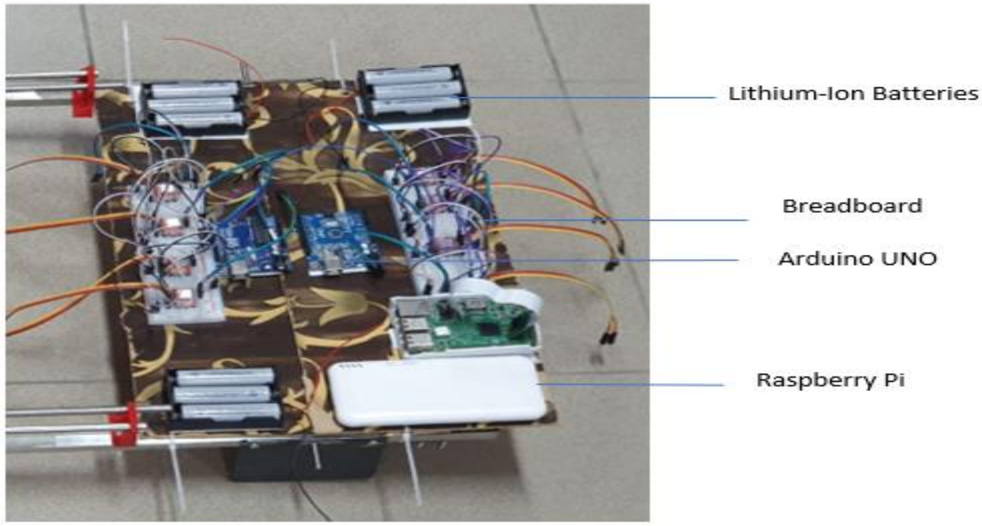


Figure 12 Electronics Circuit Setup

## 3.2 Robot Design

### 3.2.1 Chassis

The chassis is designed in the shape of a rectangle made up of Stainless Steel 201 grade extrudes, joined through bolts and mild steel re-enforcements at the corners. The stainless steel extrudes used have a cross section of 12.7mm x 12.7mm and gauge size of 18 (1.2mm thickness). The dimension of extrudes used in sides of chassis is 760mm while those used in front and back are 406.4mm in length. Each extrude shares 2 bolts and 1 mild steel plate, having 2.5 mm thickness, at each end which helps in preventing failures due to stress concentrations under high impact scenarios.

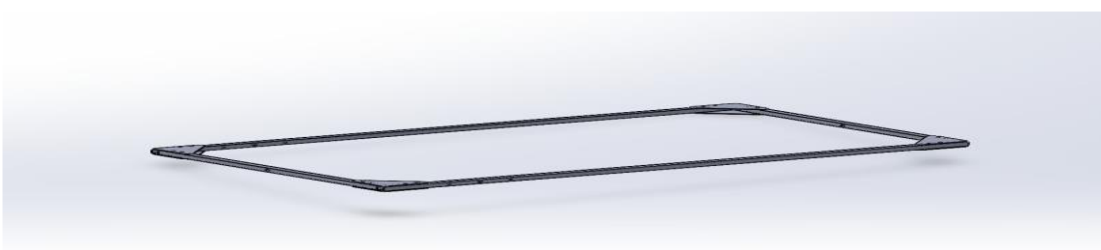

Figure 13 Chassis Main Frame

All the revolute joints are made as pin joints, using mild steel pins each having 4.7-4.8 mm diameter. The holes for pins were made using HSS Carbide drill having 4.75mm diameter on a drill press. The pins are locked in the lateral motion using snap locks, having diameter of 4mm, at one end and the pin head at the other end. This ensures free rotation of suspension joints without inducing any lateral motion. No bush or bearings have been used in the pin joints due to space constraints. The required friction reduction is achieved by lubricating using engine oil.

### 3.2.2 Suspension Mechanism

The main frame comprises of 2 side links and 2 horizontal links. It is supported by six links and 1 bracket on either side. One four-bar linkage consists of a vertical link, upper and lower diagonal links and a bracket. The bracket serves as a common effective link between two four-bar mechanisms This assembly of integrated four-bar linkages serves as a shock absorber. The bracket is attached to the frame using a pin joint. The pin joint restricts 5 degrees of freedom but allows rotation about the axis of the pin. This helps the frame maintain stability on an uneven terrain.

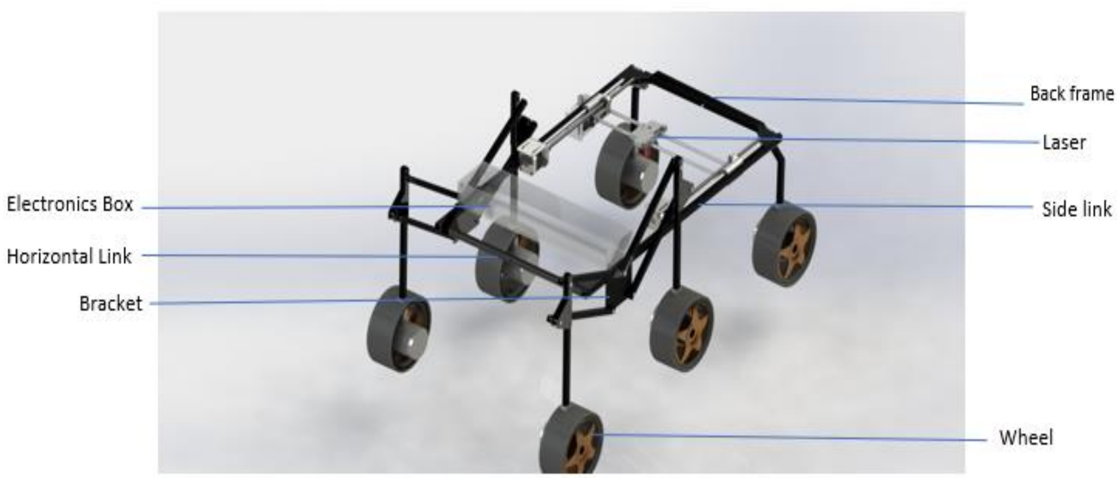


Figure 14 Chassis Components

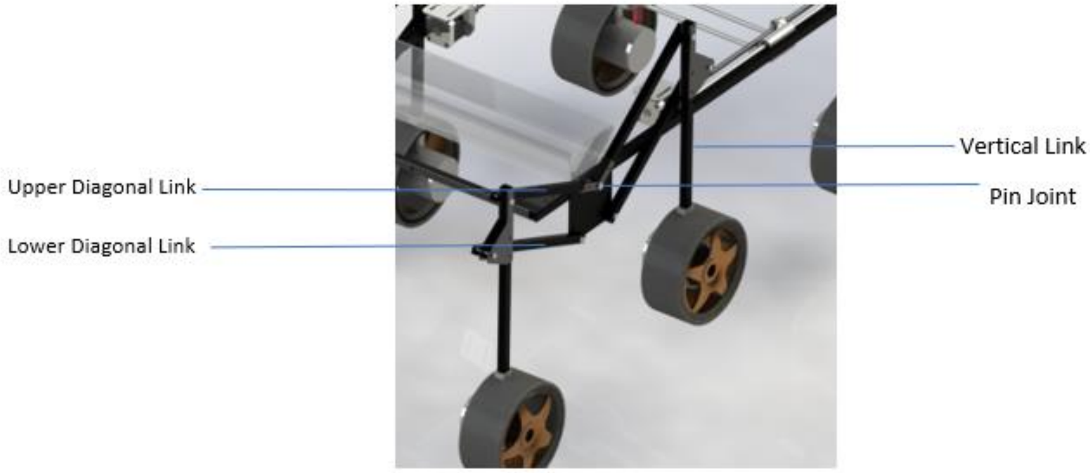


Figure 15 Suspension Components

When the robot encounters an obstacle, a moment force is applied that rotates the 2 four-bar linkage assembly about the pin axis. As a result of this moment, the two vertical link always translate in the opposite direction. This relative motion of the two links serves as a damper to dissipate the energy of the shock.

Similar mechanism is used in the back frame. The pivot of the back frame is pinned at the pivot of the frame. The pin joint allows rotation about its axis. The allowance helps absorbing the effect of obstacles and unevenness while keeping all the wheels in contact with the ground to reduce fatigue and ensure stability of frame mounted with laser and electronic equipment.


Figure 16 Suspension Backframe

### 3.2.3 Manufacturing

Thee manufacturing procedure was designed to be as convenient as possible to save manufacturing cost and time. The manufacturing processes that were used in the project were metal/wood/plastic cutting, metal/wood/plastic drilling, metal welding and turning. Grinding operations were also used where better surface finish was needed. Stainless steel 201 grade extrudes having 20ft length per piece were purchased from market. They were cut in required sizing using metal grinder. The holes for bolts were drilled using HSS carbide drill having 4.75mm diameter. Single drill bit was used in the entire manufacturing process for bolts as well as pins to maintain uniformity in the holes. Cutting/griding and drilling served to be the basic manufacturing processes for the project after which the project was moved to assembly stage. In the assembly stage, all the parts were assembled together using bolts, pins and welding as per need.

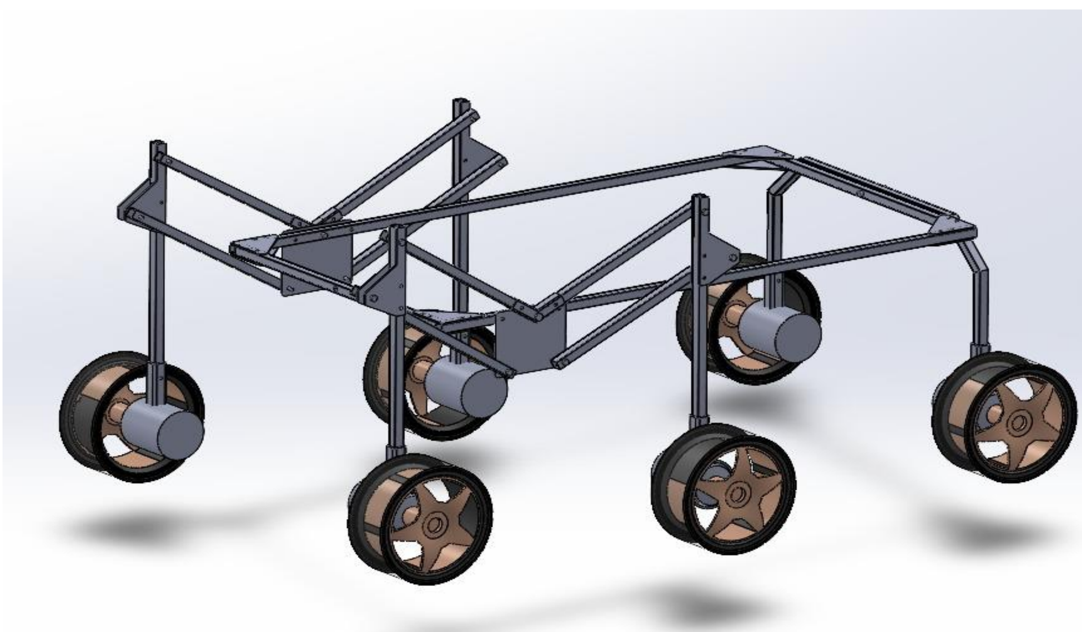

Figure 17 Complete Robot Assembly

### 3.2.4 Wheels

The wheels of the robot are designed to be flexible and self-damping, by taking advantage of their geometry and material. The geometry of the wheel utilizes optimal amount of the material to transfer all the stresses from circumference to the shaft of the wheel. This is insured by parabolic curves that connect the circumference of wheel to its shaft axis. To ensure optimal friction at the point of contact of wheel, rectangular extrudes have been given on the circumference of the wheel which increase the contact area between wheel and ground.

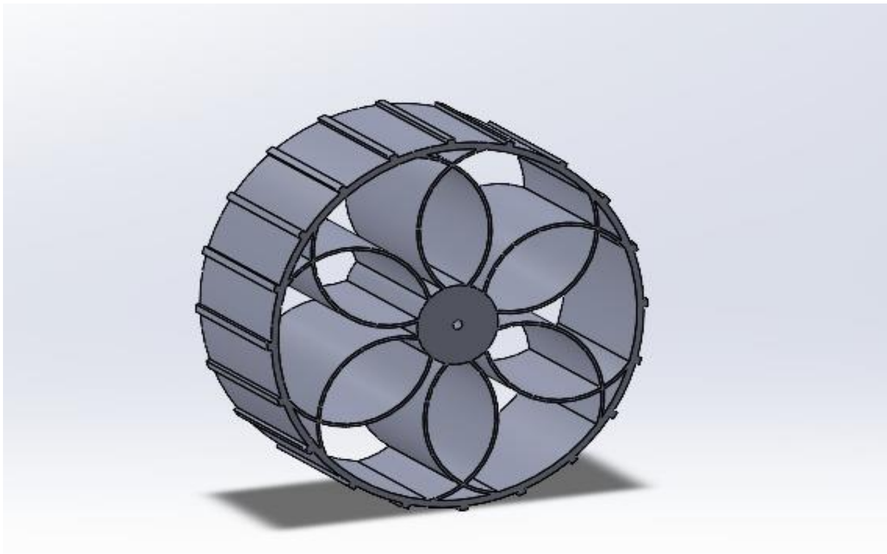

Figure 18 Custom Wheel Design

The material used for wheel manufacturing is TPU (thermoplastic polymer). The material ensures that each wheel has sufficient amount of elasticity, which serves to give smooth drive and at the same time it induces damping factor too. The technology used wheel manufacturing was additive manufacturing technology because it gives accurate control on design of object. The wheel was designed in solidworks and then printed using a locally available 3D printer.

## 3.3 Electronics

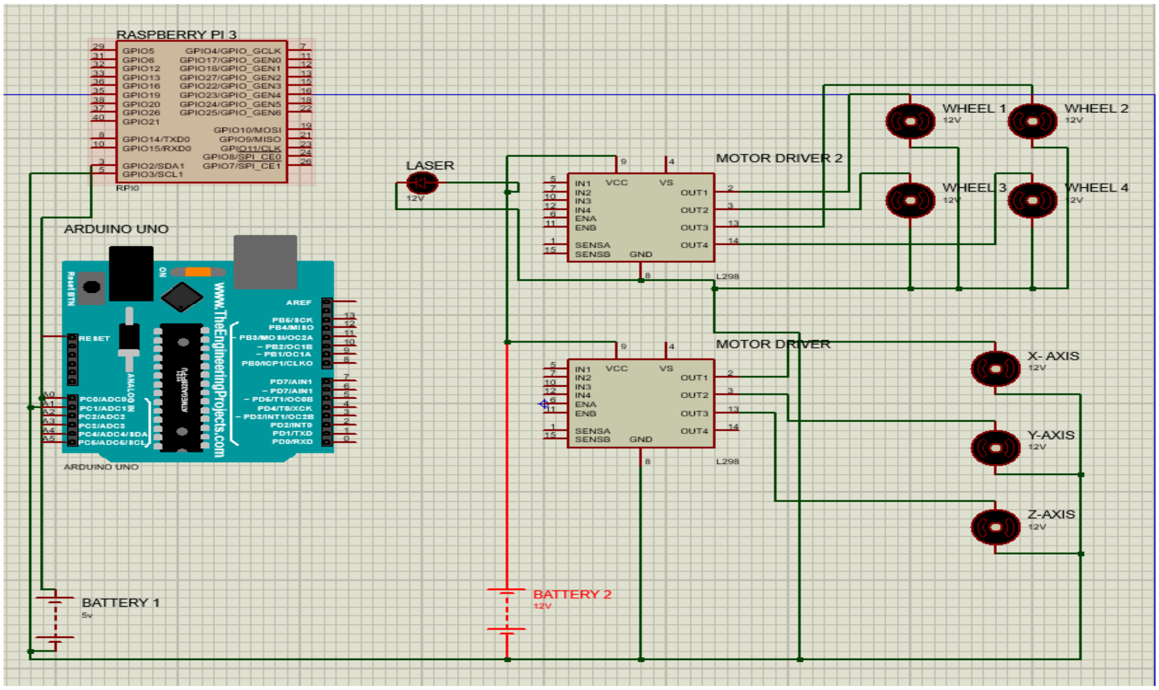


Figure 19 Electronic Circuit Diagram in Proteus

The autonomous weeding robot has a complex set of electronics involved with components with different power and voltage requirements, therefore to it has two independent circuits. These are represented in the diagram below.

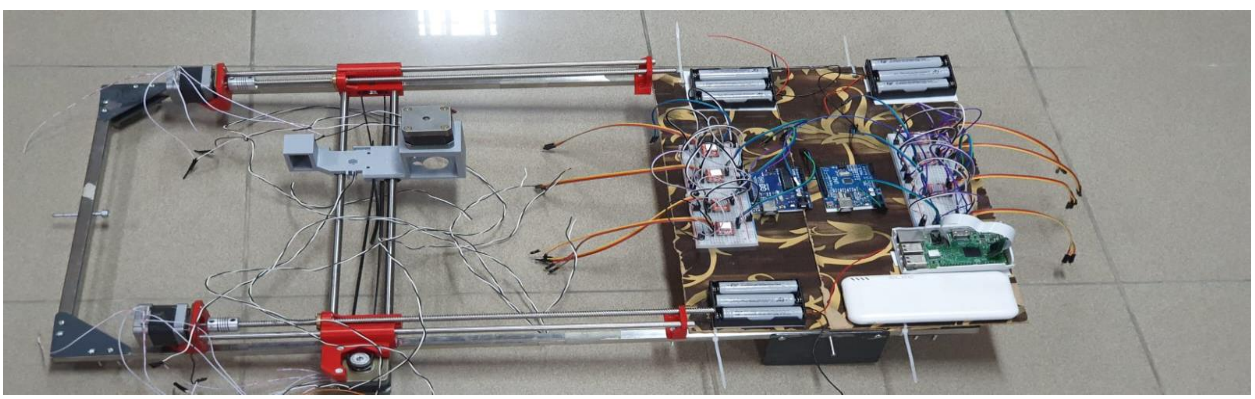

Figure 20 Electronics Circuit on Chassis

The 5V circuit is powered by a 10,000mAh power bank. It will be powering the following: raspberry pi, two Arduino UNO, Pi cam, 12MP camera and rotary encoders. All of these are lower power components therefore current is not a huge concern in this circuit. The 10,000mAh power bank is ample for continuous operations of the circuit for up to 7 hours.

Whereas the 12V circuit is powered by Lithium-Ion cells. Each cell rated at 2000mAh can produce a voltage of 3.7V and 5A max current output. A set of 3 cells connected in series will make a set of cells. Each set of cells will produce 11.1V and 5A maximum current. 3 sets of cells combined in parallel will produce 11.1V and 15A maximum current. This brings the combined power rating to 18000mAh. The circuit will be powering four 12V stepper motors to laser actuation, four 12V stepper motors for robot movement and a 12V laser. The maximum current requirement for this circuit is less than 13A.

### 3.4 Electronic Control System Design

The autonomous weeding robot has a simple electronic control setup. For robot path planning and line following Raspberry Pi will receive information from the pi cam and rotatory encoders. This will be processed by the microcomputer, and it will control robot actuation via Arduino Uno, which will control four stepper motors responsible for actuation of the robot. Similarly, when weed is detected using the 12MP camera, the robot stops. Raspberry Pi will process the image and generate the coordinates of the weed. These coordinates will be fed to the second Arduino which will then navigate the laser to that point using stepper motors. Once the laser is on top of the weed, the laser will be gradually lower till the point where IR sensor is able to sense it. At that point the laser will stop moving and the weed will be eliminated using the laser

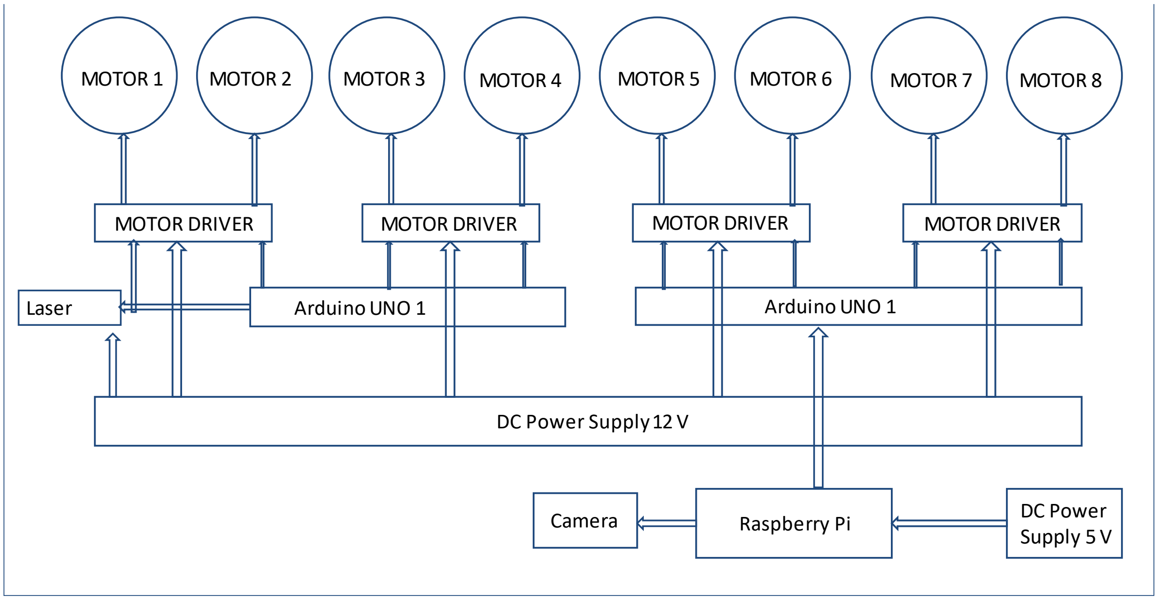


Figure 21 Control System Layout

### 3.4.1 Microcontrollers Setup

- Raspberry Pi runs Linux based operating system Ubuntu. Two cameras are connected and configured with the raspberry pi, one Pi cam with 5 Mp resolution and the other a USB webcam. The raspberry pi also controls two Arduinos using serial communication I2C.
- ROS also runs on the raspberry pi which is connected to a remote master laptop using the ROS Master/Slave network communication. Raspberry itself is controlled remotely by a Linux based laptop using the SSH protocol where both are connected to the same internet network.
- Both of the Arduinos are controlled by Raspberry Pi using rosserial_arduino library which allows serial communication between the two microcontrollers through ROS. One Arduino is used to control the 4 wheels motors and the other controls the 4 laser actuation motors. The direction and step pin of the motor driver of each motor is connected to Arduino as well as the digital output pin of the 4 wheel encoders.

### 3.4.2 Stepper Motors

4 stepper motors, NEMA 17, are used to drive the robot wheels and the laser actuation mechanisn. The choice of stepper motor instead of dc motors for robot drive is based on low rotational speed requirement without comprimisng the available torque to drive the chassis. In order to reduce the speed of a dc motor, pulse width modulation is used which reduces the current input to the motor thereby reducing both speed and torque. However, a stepper motor is able to operate at lower rpms while also providing high torque. Stepper motors are controlled by the A4988 motor drivers through arduino.

| | |
|---|---|
| Steps per Revolution: | 200 steps |
| Rotation per step: | 1.8° |
| Operating Voltage: | 12 V |
| Current Drawn: | 1.4 A |
| Stall Torque: | 1.27 Nm |

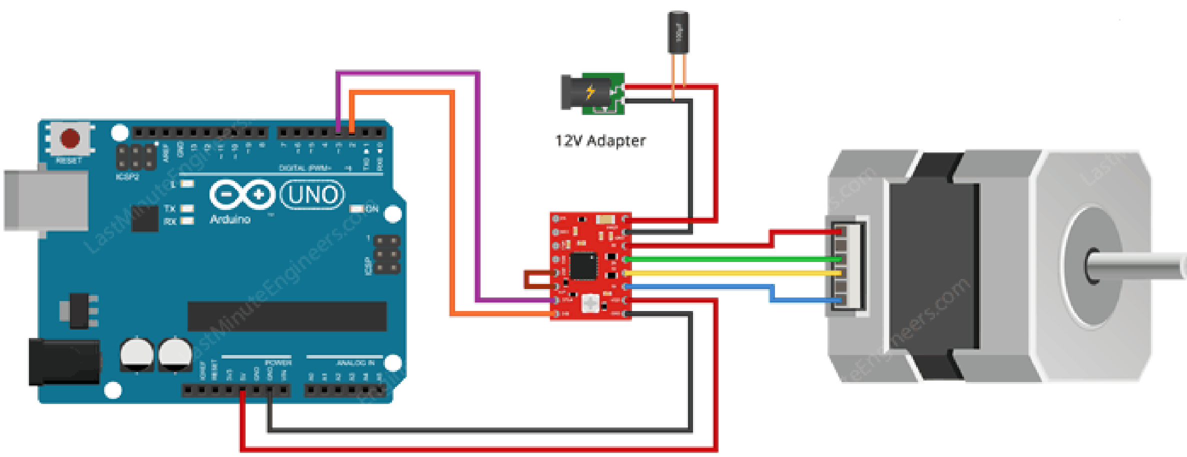


Figure 22 Stepper Motor Connection with Driver and Arduino

### 3.4.3 Stepper Motor Driver

A4988 driver module is used for each individual stepper motor connected through Arduino. The motor driver also has a heatsink to prevent overheating and current limiting potentiometer screw to control the current to the motor.

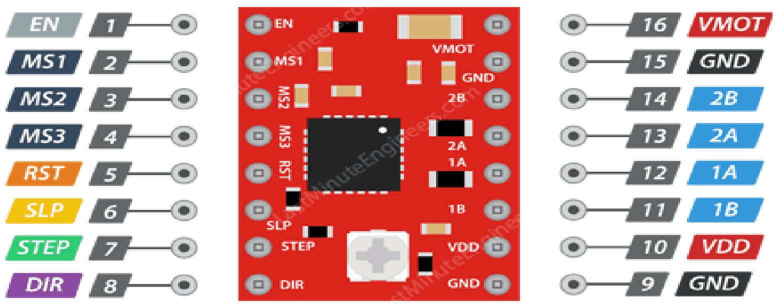


Figure 23 A4988 Motor Driver Pin Layout

Following specified pins are used

**STEP**: Signals the driver to take a step by energizing the coils in a specific sequence. Frequency of pulses controls the motor speed.

**DIR**: Controls the direction of rotation of motor shaft, by setting pin to either logic high or low.

**VMOT, GND**: VMOT pin supplies power to the motor through 12V supply and GND pin provides the ground reference of motor and driver.

**VDD, GND**: VDD supplies power to the logic circuitry through Arduino 5V connection and GND provides reference for driver and Arduino.

**1A, 1B, 2A, 2B**: Control the current flow through the coils of the motor for micro-stepping by alternating current to the two coils and drive the motor.

### 3.4.4 Wheel Encoders

Wheel encoders are rotary encoders installed on the motor shaft. They determine the distance and position moved by counting the wheel rotations. The rotary encoder used gives 20 pulses per revolution. The speed sensor gives an output when light is blocked through the encoder and counts the number of pulses received during one revolution. This data is processed to determine the robot’s speed and position, known as odometry.

### 3.4.5 Mechanical Limit Switch

Limit switches are electromechanical devices that consist of an actuator that is mechanically connected to an electrical switch. When the switched is pressed, it gives an output to stop the motor. Limit switches are used in the laser actuation to turn off the motors when laser has working area limit. They are also used to calibrate the zero position of the laser motion when the switch is pressed against it.

### 3.4.6 IR Sensor

In order to locate the weeds in z-axis, a depth camera is required which greatly exceeds the project budget. The two axes for laser motion to detected weed coordinated is determined by a regular camera. However, to detect the height of the weed from the ground, an IR proximity sensor is used. When the sensor is near a weed, it gives output to stop the laser motion in z-axis and the laser is fired at the weed to remove it.

## 3.5 Laser Actuation in Three Axes

### 3.5.1 Laser Actuation Design

The proposed design of the Autonomous Weeding Robot has a 3D laser actuation module attached to it. This module is usually used in 3D printers. The module consists of stepper motors, smooth rods, and power screws. All of these are held together with 3D printed PLA parts. As shown in the figure below, the smooth rods provide structural stability whereas the power screws are used to transmit rotational energy from the motors.

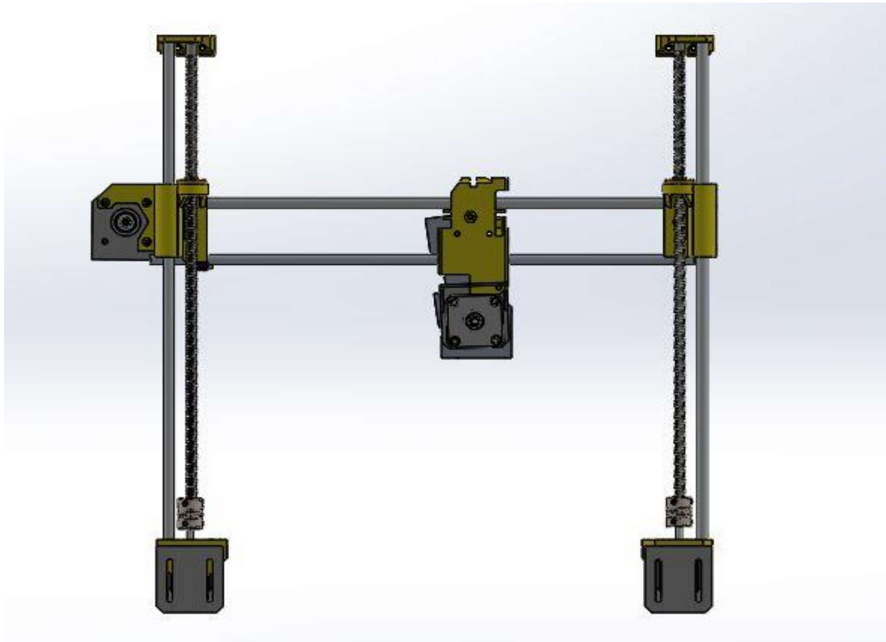

Figure 24 Top View of Laser Actuation Mechanism

For actuation of the laser in X axes, two stepper motors will rotate at the same speed and in the same direction. The power screw will rotate which in turn will allow translational motion of the central console. The central console has the laser in it.

In order to achieve laser actuation in Y axes, the central console has a stepper motor which will allow translational motion of the laser holder using a belt and pulley mechanism. The laser holder holds the laser and holds everything needed from laser actuation in Z axes.

The stepper motors are controlled by Arduinos, and they are powered by lithium-ion batteries. The proposed system needs to be equipped with sensors to detect its height from the weed.

### 3.5.2 Laser Actuation Mechanism

The way the proposed system works is that the Robot recognizes the weed within the crop. The robot then determines its position and converts it into coordinates. These coordinates are then fed into the Arduino, which will then actuate two motors to navigate the laser in X axes and then one motor to navigate in Y axes thereby bringing it on top of the weed by

X and Y axis motion. Once the laser is on top of the weed, the laser will be brought down in Z-axis in a controlled manner using a fourth stepper motor. An IR sensor is placed right next to the laser. The moment the weed is detected by the IR sensor, it will stop the motor thereby stopping the vertical movement of the motor. The Algorithm will now turn on the laser for exactly 2 seconds. This will eliminate the detected weed in the crop. Then it will return to its original position by following the same line of path.

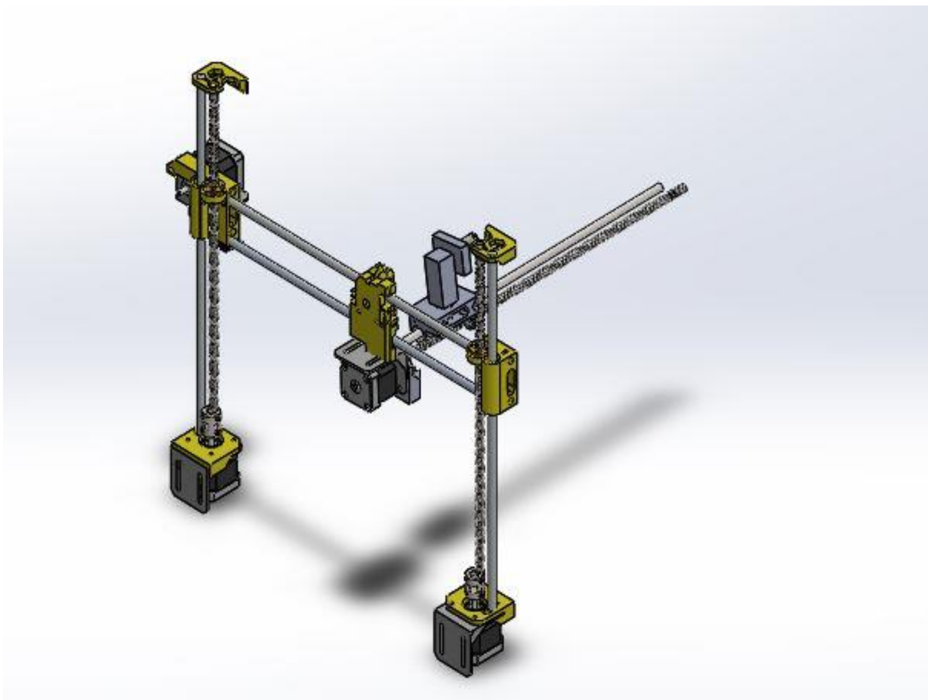

Figure 25 Isometric View of Laser Actuation Mechanism

### 3.5.3 Resolution of Laser Motion

*3.6.5.1 Y Axis and Z Axis*

The laser motion along the y and z axes are controlled by lead screws coupled with stepper motor. In order to move the motor to detected weed coordinates, the coordinates are converted to steps of the motor.

Lead Screw Specifications are,

Diameter: 8mm

Number of Threads n: 1

Pitch p: 2mm

The distance (lead) moved by nut attached to lead screw is equal to the pitch of the lead screw multiplied by the number of threads

$$\text{Lead L} = n \times p$$

$$\text{L} = 1 \times 2mm$$

$$\text{L} = 2mm$$

Thus, the distance moved by the mechanism by revolution of the lead screw is 2mm

$$\text{Number of steps per revolution of Motor } N = 200 \text{ steps}$$

$$\text{Resolution } = \frac{steps}{mm}$$

$$\textbf{Resolution } = \frac{\mathbf{200}}{\mathbf{2}} = \mathbf{100 \text{ steps per mm}}$$

In order to move 1mm along y and z axis, 100 steps of the motor are required

To convert desired position in mm to steps of the motor

$$\textbf{Required Steps } = \textbf{y Coordinate } \times \mathbf{100}$$

The minimum distance which can be moved along y and z axis is based on distance moved per single step of motor

$$\frac{1}{100}\text{mm} = 0.01\text{mm}$$

The laser can move a minimum of 0.01 mm in y and z axis

*3.5.3.2 X Axis*

The motion of the laser in x axis is controlled through a teeth pulley GT2 attached to the stepper motor over which a timing belt is tied. Micro stepping mode of half step is used to provide better resolution and accuracy to the laser motion. This is achieved by setting the pin M01 of the specific driver as high. The specifications are,

Number of steps of Motor N = 200

Micro stepping Factor f= 2

Pitch of Timing Belt p = 2 mm

Number of teeth on Pulley $N_t$ = 20

The formula for the resolution or steps per mm for the belt and pulley mechanism is,

$$\text{Resolution } = \frac{N \times f}{p \times N_t}$$

$$\text{Resolution } = \frac{200 \times 2}{2 \times 20}$$

$$\textbf{Resolution } = \textbf{10 steps per mm}$$

Thus, 10 steps of the motor are required to move the laser 1mm along x-axis

To convert X coodinates of the weed into steps, following formula is used

$$\textbf{Required Steps} = \mathbf{10} \times \textbf{Xcoordinate}$$

The minimum distance which can be moved along x axis is based on distance

moved per single step of motor is $\frac{1}{10}\text{mm} = 0.1\text{mm}$

The laser can move a minimum of 0.1 mm in x axis

### 3.6 Path Planning

The navigation of the autonomous weeding robot requires the successful of the following tasks, perception, localization, path detection and motion control [13].

#### 3.6.1 Perception

A single camera is used to locate the path the robot should undertake while eliminating the need of depth analysis. The first step is to locate the row of crops in an agriculture field. The image is converted from RGB to HSV color space where a range of HSV values is defined based on the crop color. The image returned is a binary image that reduces the original image to crop rows only. Then noise is reduced by dilation, erosion and size filtration of crops [16]. So, the robot sees a black and white image consisting of crops rows only.

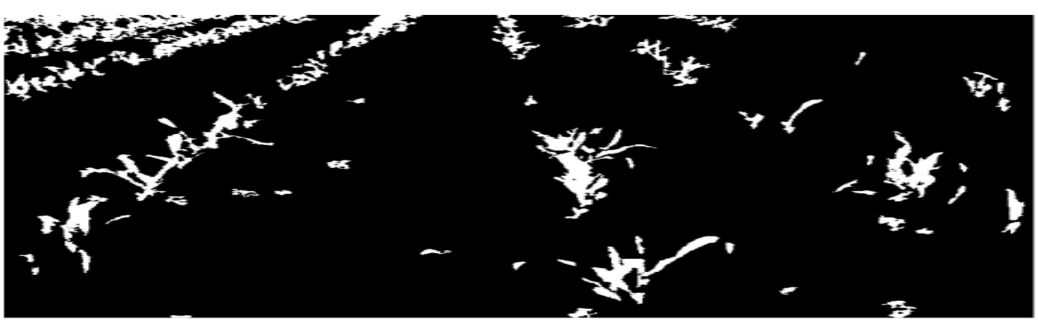

Figure 26 Binary Image showing Crop Rows

### 3.6.2 Localization

Localization is based on simple odometry where the distance travelled along a row is calculated based on the rotation of the wheels. The length of the row is recorded and is used for future reference when following more rows. The position of the robot at any instance along the row can be determined. At the end of each row, the robot performs a 180-degree using skid steer and enters the next row. Since skid steering causes slippage between the wheels and the ground, it introduces inaccuracies in the odometry data. It can be mitigated by localizing the robot again based on the row it is entering [23].

### 3.6.3 Path Detection

After a binary image with crops rows is obtained and the robot has localized itself according to the row, the next step is to determine the path to be following along the row. The objective here is for the robot to align its center with the center line of the crop row.

Crop line discontinuities may occur in a field environment as a result of improper seeding. To locate and connect line segments in the image, use of the general line detection approach Hough transformation is recommended [15]. The crop center line is also extracted using Hough transformation.

### 3.6.4 Motion Control

Once the path through the field has been obtained, the next step is to implement the motion control to make the robot follow the desired path along the center of the crop row. This includes turning the robot either right of left through skid steering to such an angle that center of the chassis is ideally aligned with the center of the row. Then the next step is to simply follow the straight row unless any deviation occurs. The angle of the crop row deviation can be determined and the robot is turned at the required angle to align with deviated row [24]. A correcting mechanism through motor controls is also used to the limit deviation when following straight line crops and avoid contact between wheel and crop. The wheels turn to enter the next row and the process is repeated.

### 3.6.5 Simulation using ROS and Gazebo

ROS (Robot Operating System) is a framework for developing robotics control models and applications by providing hardware drivers, sensors, and algorithms. Gazebo is a 3D physics-based simulation tool used to simulate robots in specific environment. Together, ROS and Gazebo provide a powerful platform for simulating mobile robots.

The first step is to create a Unified Robotics Description Format (URDF) files that contains all the links and joints of the robot. URDF is an XML format file that describe the geometry, kinematics, dynamics, sensors and controls of a robot to be used by ROS for simulation. The frame and the wheels are described as links whereas the connection between them is describe through fixed joints. Non-fixed joints are also used such prismatic for laser motion, revolute for suspension motion and continuous for wheels.

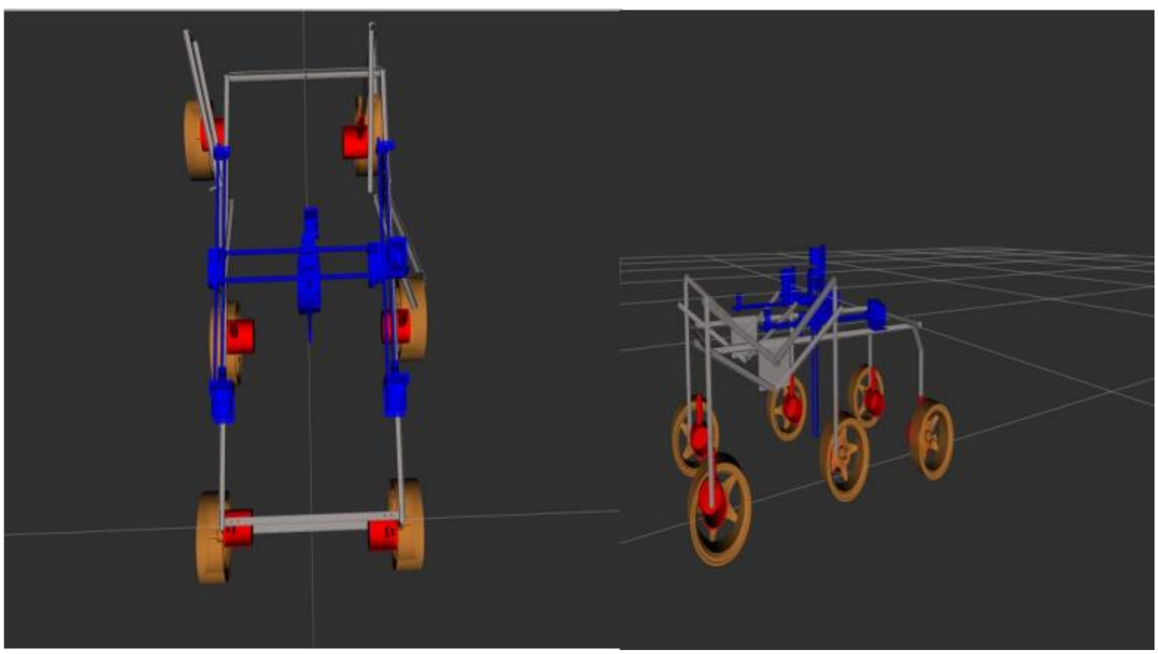

Figure 27 URDF Model of Robot in rviz

Different sensors and controllers are integrated with URDF file to link the robot in ROS with the gazebo environment. A custom agriculture world is used in gazebo to mimic the rough agriculture conditions the robot has to move on. Skid steering controller is interfaced with gazebo by describing the location of the robot wheel joints and physical dimensions [25]. A node file is created which commands the robot to move with a specified velocity to follow the crop row. The results obtained from the simulation help troubleshoot and improve the path planning algorithm before it is implemented on the real robot.

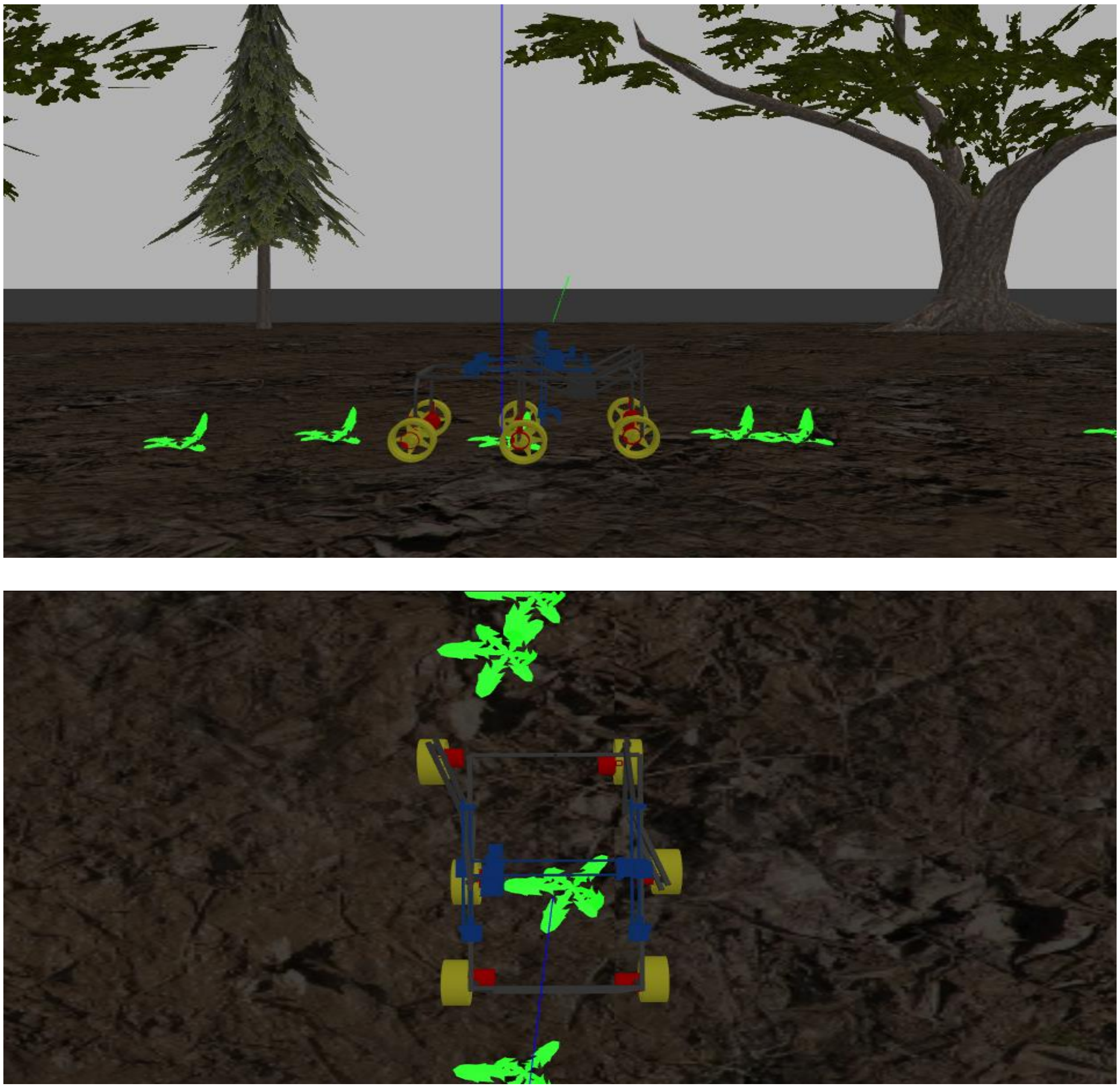

Figure 28 Simulation of Robot in Agriculture world in Gazebo with Crop Rows

### 3.7 Weed Detection

The weed detection mechanism of the autonomous weeding robot uses a regular 8MP 30FPS camera, to detect weed in real-time and send its exact coordinates of the middle of the weed to the Raspberry Pi. In order to avoid latency related issues, the weed detection algorithm is coded in C++ using the OpenCV library.

#### 3.7.1 Color Filter:

The image received from the cameras is first filtered on the basis of color. Since the weed itself is a shade of green, after applying the filter only green color would be left.

#### 3.7.2 Greyscale:

After filtering out all the colors other than green, greyscale is applied to the received image.

#### 3.7.3 Adding Blur:

Blur is added to the image to improve edge detection of the program. A very slight blur is used to ensure there is no major loss of quality in the image.

#### 3.7.4 Canny and Dilation:

Canny edge detection is applied on the blurred image which would bring out clear outlines of the image, which is then dilated.

#### 3.7.5 Contours:

Contour is then applied on the final dilated image to distinguish regions. Contour is used to detect borders of the weed and localize them in the image. Since the crop may be green as well, therefore, to avoid hitting the crop, the weed will be distinguished from the crop based on size. Considering weeds are much smaller than crops, the size of the detected objects will be calculated to determine whether it is a weed or not.

# CHAPTER 4: RESULTS AND DISCUSSIONS

## 4.1 Chassis Stress Analysis

A stress analysis is necessary to ensure that any link of the chassis frame does not undergo deformation or failure. Since the robot is designed and manufactured to traverse rough agriculture terrains, it is important to take into account the impact and shock loadings that it may encounter in the field. Moreover, the robot may also need to climb steep slopes in field which further increase loads on the main frame [26].

A static structural analysis is carried out in ANSYS to determine the maximum stresses. Instead of simulating the whole chassis for stresses, one of the links most susceptible to failure is analyzed. It is the sides links attached to the main frame which host the 4-bar suspension mechanism and thus are likely to have higher stress concentration. Due to symmetry of the main frame, only one link is simulated since identical results would be obtained.

### 4.1.1 Equivalent Stress

Equivalent or von-Mises stress is determined for an applied load equal to estimated robot weight of 20kg. Von Mises stress measures the stress intensity at a point in the material, taking into account the combined effects of all three types of stress (tensile, compressive and shear). The maximum stress in the side link is determined to be 186 MPa which is located near the point of attachment of the 4-bar linkage suspension. The maximum stress is tensile in natures and tends to elongate the link.

The yield strength of stainless steel is 205 MPa. Thus, link is not likely to undergo failure because of stress exceeding the yield strength. The factor of safety of the main frame comes out to be 1.1 which is not high but taking into account that the applied load is much higher than actual conditions, the von-Mises stress plot provides a reliable estimate that the chassis is safe for operation in agriculture fields.

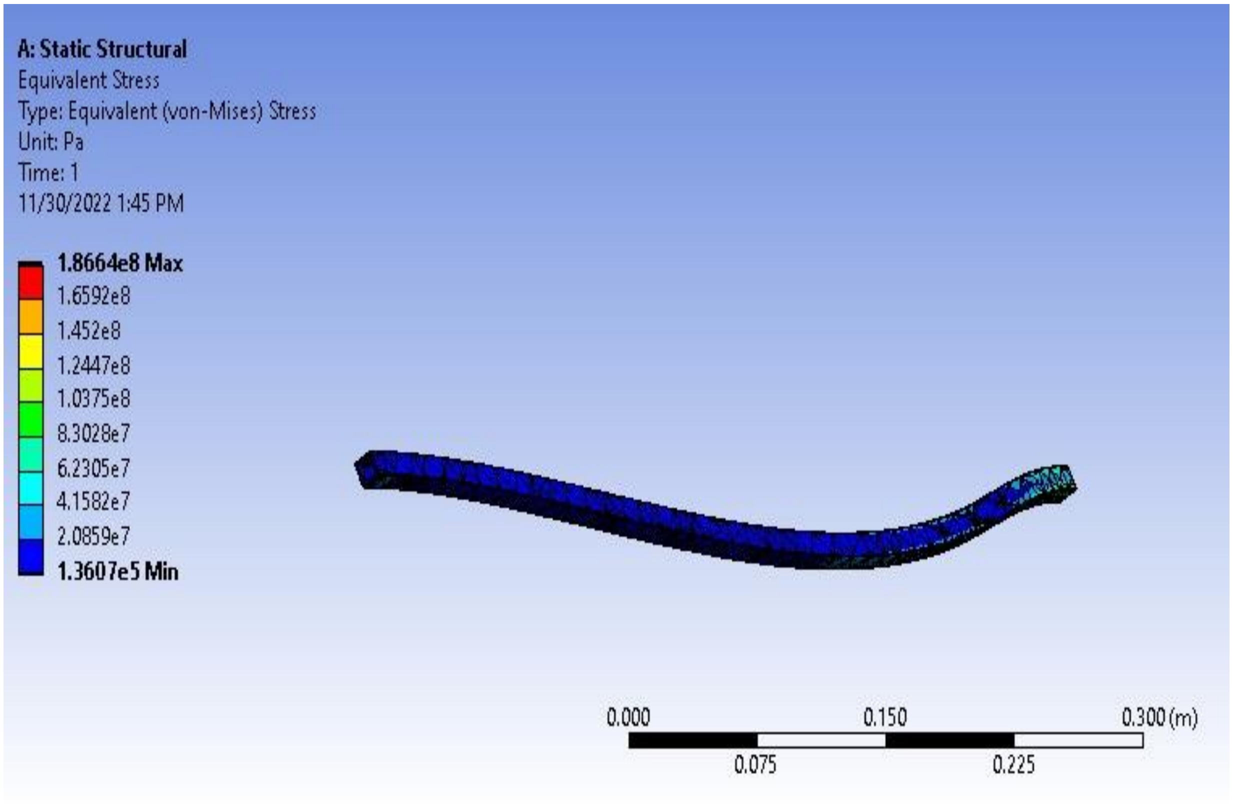


Figure 29 von-Mises Stress Plot for Side Link

### 4.1.2 Shear Stress

Though von-mises stress analysis provides an accurate result that the chassis will not undergo deformation, it is still important to simulate the shear stress in the link to determine the likelihood of shar failure. It may cause the link to rupture or break along the plane parallel to its face due to excessive bending.

The maximum shear stress is determined to be 8.73 MPa and is compressive in nature as indicated by the negative sign. It indicates that the link is being compressed along the plane of the shear stress and the material of the link is being squeezed together. As expected, maximum shear strength is also obtained near the attachment of the suspensions links, thus making it more likely to fail than other points of the frame.

The shear strength of stainless steel is 74.5 MPa and thus the possibility of shear failure is very unlikely. Factor of safety obtained in case of shear stress is 8.5, a high value indicating close to zero probability of shear failure. Thus, the robot chassis is safe from both tensile and shear stress failure and is suited for its agriculture application.

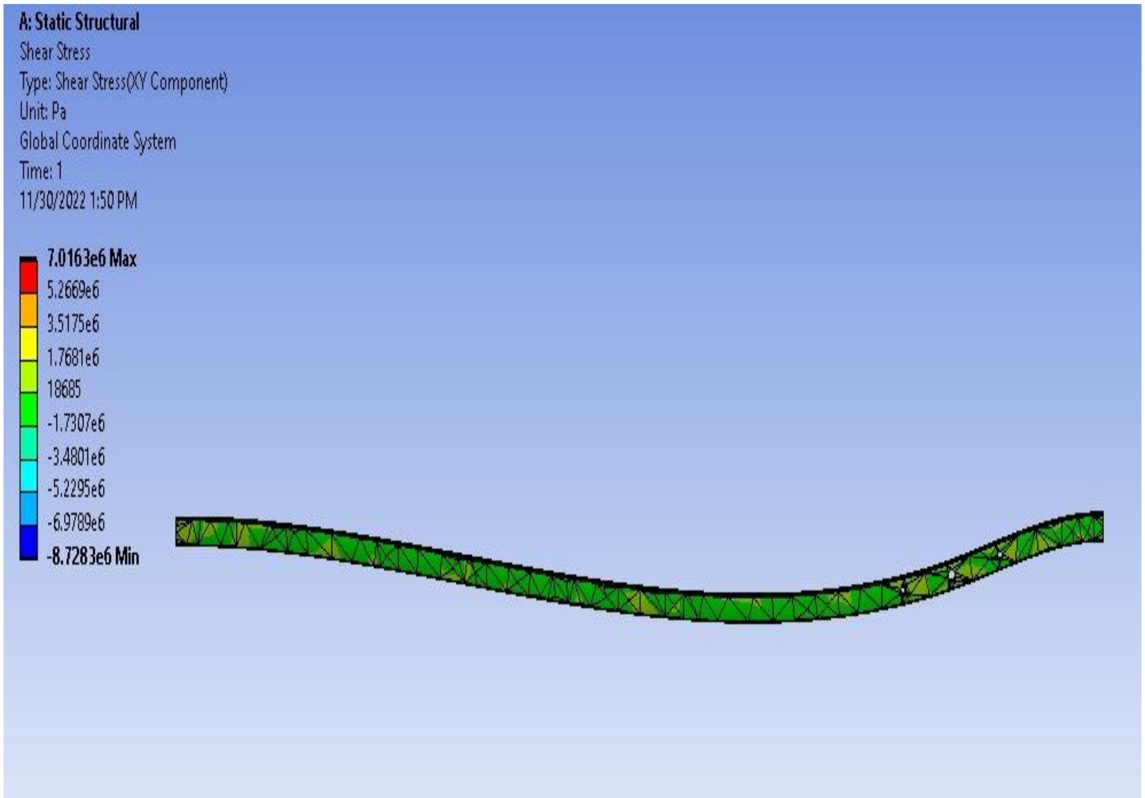


Figure 30 Shear Stress Plot of Side Link

## 4.2 Deformation Analysis

The maximum possible deformation was calculated by simulating the application of 20kg load on a single joint in the side link. It is to be noted that the actual total load on the frame is not more than 10kg and that load is distributed on 17 links. To ensure maximum durability, analysis was performed simulating extreme conditions. The maximum deformation was observed near the centre of the side link. The magnitude of maximum deformation was 0.6mm at the maximum point and was simulated to be zero near the end points.

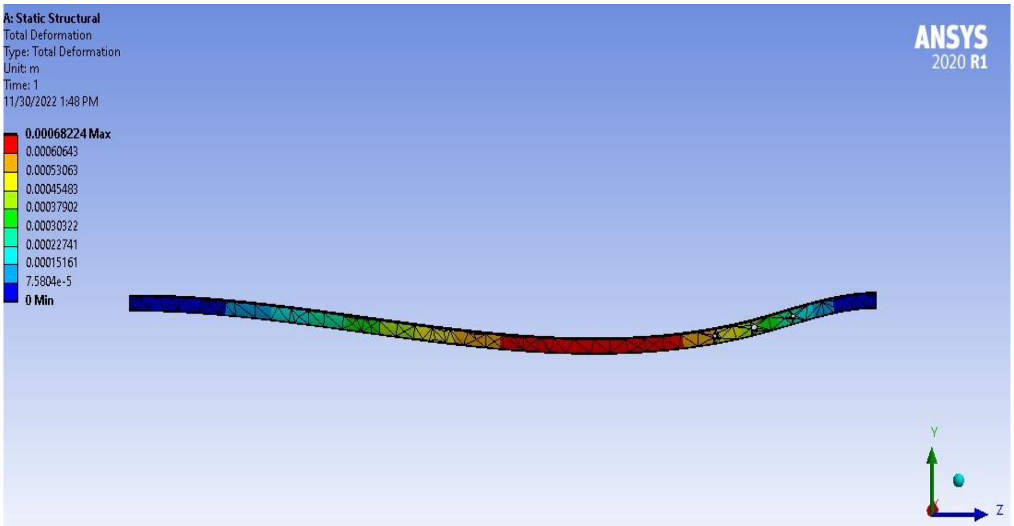


Figure 31 Deformation Plot of Side Link

## 4.3 Fabricated Model

The fabricated model consists of chassis attached to both suspension systems (front and rear) by means of pin joints. The rectangular frame is utilized to accommodate all the circuitry and the weed killing mechanism. All the fixed joints are fabricated using nut and bolts of different sizes, according to the need, which not only ensures strength but gives flexibility in terms of assembling and disassembling. The laser killing mechanism is directly attached to the chassis by means of nut and bolts while all the circuitry rests on a wooden ply board having 3mm thickness, and then the ply board is attached to the chassis by means of nut and bolts.



Figure 32 Comparison of Robot Design Model and Fabricated Frame

The Wheels are attached to the suspension through motor holders. The holders are 3D printed based on the dimensions of the motors. Then the holders are inserted into the legs of the main frame and tightened with nut and bolt. A 8mm shaft is pressed fitted into the wheels. The 5mm motor shaft and 8mm wheel shaft are coupled together by a fixed coupling. The final assembly of the robot with wheels is shown in the figure

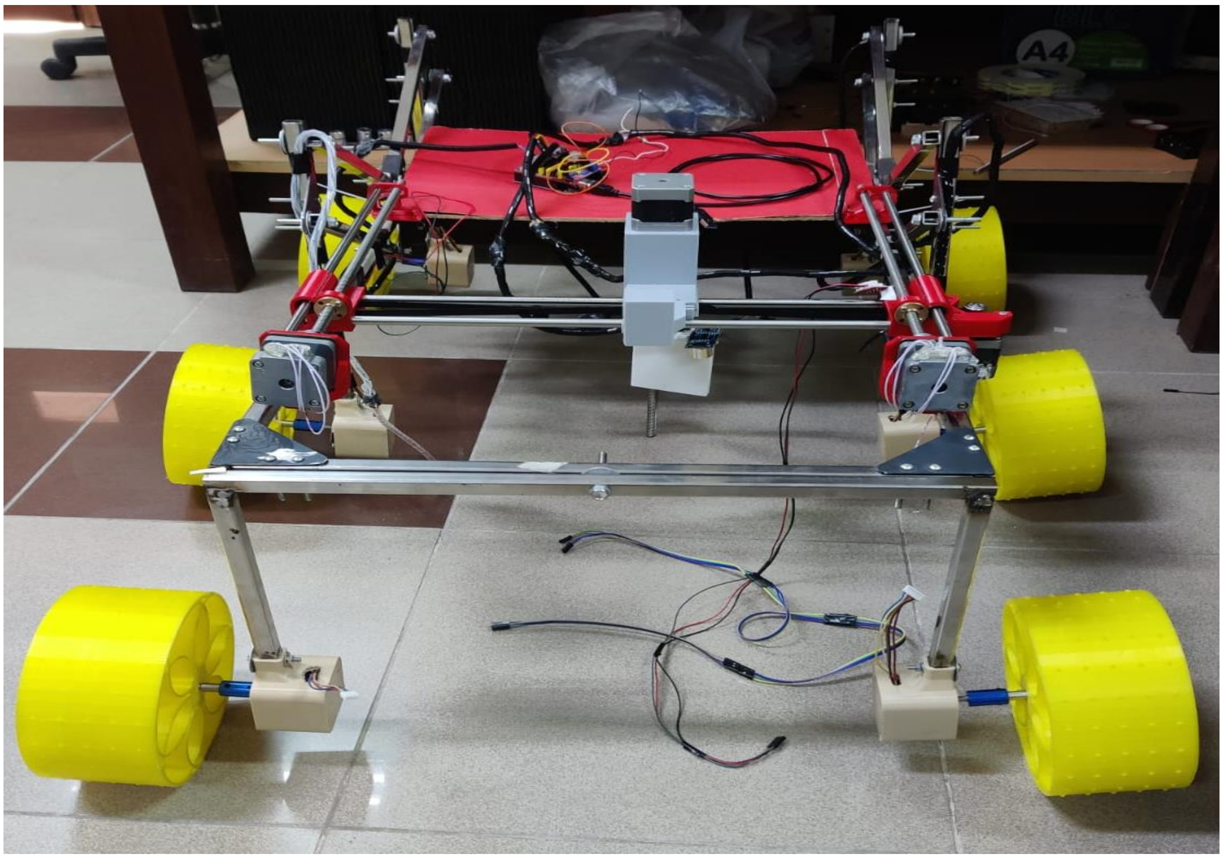


Figure 33 Fabricated Robot with Wheels Attached

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The purpose of this project is to introduce automation in agriculture, specially to weed removal. A six wheeled mobile robot is designed and manufactured for this objective. The design strategy is for the robot to be able to move different agriculture conditions with high stability without the risk of toppling over. By moving smoothly across rugged terrains, the robot can perform its intended purpose of weed detection and removal. The weed removal method is based on three axis motion of a laser.

The total weight of the robot including the accessories is 12kg. The factor of safety in design comes out to be 2 for equivalent stress and 8.5 for shear failure. The length of the chassis is 406 mm and the width is 760 mm with a height of the 320 mm from the ground. The robot is equipped with a novel 4 bar linkage suspension for effective stability through lateral motion. The wheels are 3d printed from TPU material for on ground damping and smooth motion.

The method used for navigation is to detect and follow the rows of crop in a farm. As the row of planted crops turns, so the robot to align its center with center line of the row. At the end of row, the robot performs a skid steer turn to enter the adjacent row. Weed detection is based on classification of the objects detected based on size. Too small contours are ignored as noise, while bigger contours are termed as crops leaving behind weed. The laser is programmed to move to the coordinates of the weed and the weed is removed.

## 5.2 Benefits of Project

### 5.2.1 Novel Suspension

The suspension system consists of set of two novel double crank mechanisms, joined at a common axis via pin joint, which serve to transmit the motion induced in a wheel by a bounce to its counterpart wheel. The kinetic energy induced by bounce is damped by utilizing in the motion at the opposite end and thus gives efficient damping, keeping the central platform straight. This suspension system is inherently capable of sustaining a quarter of feet bounce without compromising on the stability of the central platform. Double crank mechanisms are an easy substitute to conventional spring damper systems which are not only very complex in manufacturing but also, they are not suitable for maneuvering in rough terrains. Because of the double crank mechanism, the robot is capable of maneuvering in fields small rocks without compromising on stability.

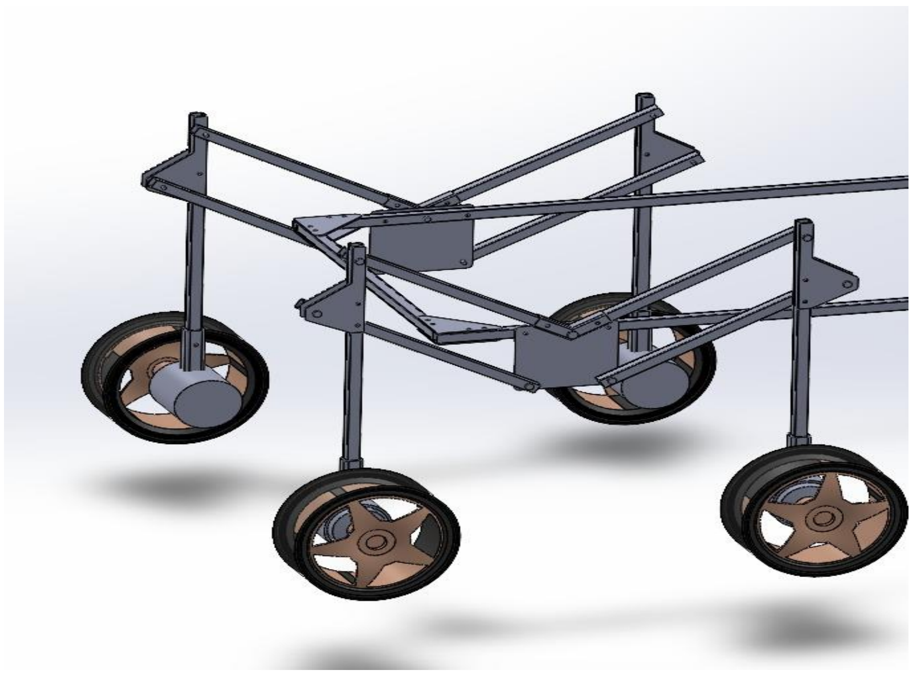

Figure 34 Four Bar Suspension Linkages

### 5.2.2 Precise Weeding

Precision weeding is being adopted as a practice around the world because of 2 significant advantages over conventional methods. First is increased yield per unit area because the efficiency of weeding process increases as the process of identification of weeds becomes efficient. Weed inflicted losses in Pakistan are estimated to be 36 million tons which corresponds to a monetary value of 3 billion dollars annually [27]. These losses are incurred due to lack of precision in weeding methods and dependence on manually operated tools. The average weed-caused crop loss is 11.5% in Pakistan [3]. Precision weeding also reduces the chances of weed survival which can be otherwise up to 45% [6].

The other important advantage of precision weeding is reduction in energy consumption. In precision practices, the weeding actuator is only activated upon detection of weed instead of drawing continuous power. This can reduce energy consumption up to 90% [8].

### 5.2.3 Autonomous Navigation

The robot can travel more quickly and precisely along crop rows owing to autonomous navigation, which reduces the amount of time and resources needed for crop management leading to reduced labor costs and high efficiency. The robot's ability to work without human assistance lowers labor expenses and enables up time for other farm activities. With no possibility of human error and uniform treatment of the crops, autonomous navigation ensures steady progress along the rows of crops.

## 5.3 Recommendations

### 5.3.1 Use of Machine Learning for Computer Vision

As far as weed detection is concerned, classification of weed and crop based on parameters related to size does not offer a flexible solution. In order to detect weed of any size, too small or large, machine learning methods are necessary. For detection of weeds in different crops, deep learning models such YOLO are preferred but require high computing power [28].

### 5.3.2 Implementation of SLAM

Although crop row detection offers a good path planning method to navigate fields and detect weed alongside, better localization and mapping techniques can help the robot adapt to different environments. Laser range detection with a Lidar can help in better positional awareness. Moreover, use of Simultaneous Localization and Mapping techniques, especially visual based such as Orb-SLAM will not only help create a map of the agriculture field but will lead to better localization as well [29].

### 5.3.3 Adjustable Chassis

Since the inter row spacing is different for a variety of crops, it is not an easy task for the same robot to navigate through different fields. A chassis of the same length which navigates and follows crop in one farm may not able to do so in other farms and might result in crop damage. Therefore, for improve functionality, it is desirable to have a chassis of adjustable length that can set according to crop and field dimensions [30].

### 5.3.4 Use of DC Motors

Another alternative to using stepper motors to drive the robot is to use conventional high torque DC gear motors with encoders. DC Gear motor are not used in the project to higher price and lack of availability. Stepper motor mainly Nema-17 acts as a suitable replacement to provide sufficient torque needed to move the robot in a controlled method while also counting the number of revolutions made necessary for odometry. DC Motors with higher torque rating would provide more stability to the platform and be able to achieve smoother motion and turning of the robot.

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