ENHANCEMENTS IN EXPLOSIVE ORDNANCE DISPOSAL ROBOT DESIGN

A PROJECT REPORT

Submitted by

SANYATJEET PAWDE [RA1711004010048]
ROHAN TEHALYANI [RA1711004010050]
MITRANSH CHOUBISA [RA1711004010058]
MAYANK KUMAR [RA1711004010064]

Under the guidance of

Dr. P. ESWARAN , Ph.D
(Associate Professor, Department of Electronics and Communication Engineering)

in partial fulfillment for the award of the degree

of

BACHELOR OF TECHNOLOGY

in

ELECTRONICS AND COMMUNICATION ENGINEERING

of

FACULTY OF ENGINEERING AND TECHNOLOGY

Department of Electronics and Communication Engineering
College of Engineering and Technology
SRM Institute of Science and Technology

S.R.M. Nagar, Kattankulathur, Kancheepuram District

MAY 2021

SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

(Under Section 3 of UGC Act, 1956)

BONAFIDE CERTIFICATE

Certified that this project report titled "**ENHANCEMENTS IN EXPLOSIVE ORDNANCE DISPOSAL ROBOT DESIGN**" is the bonafide work of "**SANYATJEET PAWDE[Reg No:RA1711004010048], ROHAN TEHALYANI[Reg No:RA1711004010050], MITRANSH CHOUBISA [Reg No:RA1711004010058], MAYANK KUMAR [Reg No: RA1711004010064]**" who carried out the project work under my supervision along with his batch mates. Certified further, that to the best of my knowledge the work reported herein does not form any other project report on the basis of which a degree or award was conferred on an earlier occasion for this or any other candidate.

Date: 20/05/2021

SIGNATURE

Dr. P. ESWARAN, Ph.D
GUIDE
Associate Professor
Dept. of Electronics and Communication Engineering

SIGNATURE

Dr. SHANTHI PRINCE, Ph.D
HEAD OF THE DEPARTMENT
Professor and Head
Dept. of Electronics and Communication Engineering

Submitted for University Examination held on in the Department of Electronics and Communication Engineering, SRM Institute of Science and Technology, Kattankulathur.

Date: Internal Examiner External Examiner

DECLARATION

We hereby declare that the Major Project entitled "**ENHANCEMENTS IN EXPLOSIVE ORDNANCE DISPOSAL ROBOT DESIGN**" to be submitted for the Degree of Bachelor of Technology is our original work as a team and the dissertation has not formed the basis of any degree, diploma, associate-ship or fellowship of similar other titles. It has not been submitted to any other University or institution for the award of any degree or diploma.

Place: SRM INSTITUTE OF SCIENCE AND TECHNOLOGY, Kattankulathur, Tamil Nadu

Date: 20/05/2021

Sanyat
07/03/2021

Sanyatjeet Pawde
[Reg No:RA1711004010048]

Rohan
07/03/2021

Rohan Tehalyani
[Reg No:RA1711004010050]

Mitransh

Mitransh Choubisa
[Reg No:RA1711004010058]

Mayank Kumar
7/3/21

Mayank Kumar
[Reg No:RA1711004010064]

ABSTRACT

This project aims to enhance the currently existing designs and technologies of Explosive Ordnance Disposal Robots,which aid in modern day battlefronts in Counter-Improvised Explosive Devices operations.The currently existing models do not incorporate on board sensors which are necessary for Counter-IED operations and certain design parameter which could help the bot in tactical environment thereby indirectly involving human and animal intervention we have proposed this conceptual model of a robot with enhanced features like Quad Track Independent Drive Mechanism, Onboard Jammer, Electromagnetic Pulse Generator, Detachable Manipulator with 6 degrees of freedom, Terrain Sustainable Power unit, Dual Virtual System Feed and Hydraulic Piston Mechanism, which eradicates human and animal intervention to a greater extent.Thus preventing loss of life.

We have realised our proposed model comprising the aforementioned features by simulation and testing of mainly the quad track mechanism, belt link and suspension stress analysis, manipulator kinematic analysis and jammer simulation.We have obtained satisfactory results like the endurance of load by the belt link till 50Kg without breaking or bending, accurate pick and place operation of manipulator and frequency selective random signal output of the jammer.

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to our guide, Dr. P. Eswaran for his valuable guidance, consistent encouragement, personal caring, timely help and providing us with an excellent atmosphere for doing research. All through the work, in spite of his busy schedule, he has extended cheerful and cordial support to us for completing this research work.

Project Group

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

COG Centre of Gravity

LIST OF SYMBOLS

F	Force, N
T	Torque ,kgcm
L	length, cm
m	mass, gm
g	acceleration due to gravity, m/s^2
θ	critical angle(angle of elevation), $^\circ$degrees
μ	coefficient of friction,dimensionless
h_{cog}	height of centre of gravity,cm
w	width of vehicle,cm
a	side length,cm

CHAPTER 1

INTRODUCTION

With the aim to enhance the currently existing designs and technologies of Explosive Ordnance Disposal Robots,which play a vital role in modern day battlefronts by detecting defusing and disposing Improvised Explosive Devices camouflaged in the environment, we have proposed this conceptual model of a robot with enhanced features like Quad Track Independent Drive Mechanism, Onboard Jammer, Electromagnetic Pulse Generator, Detachable Manipulator with 6 degrees of freedom, Terrain Sustainable Power unit, Dual Virtual System Feed and Hydraulic Piston Mechanism.

To realise the model comprising the aforementioned features we have used Autodesk Fusion360, Dassault Solidworks for CAD modelling and stress analysis; Robot Operating System, Gazebo for manipulator parameters and simulation; Eagle PCB for PCB designing; NI Multisim, Riverbed Academic Modeller 17.5 for jammer design and simulation; Arduino IDE, Serial Processing for communications and control system.

1.1 Improvised Explosive Devices(IEDs)

Improvised Explosive Devices are devices made by improvising and incorporating routine life materials into a lethal explosive/bomb units like pressure cookers, cellphones, vests ,vehicles even human and animal bodies. IED's are the most imminent threats in battlefronts as they are easily camouflaged in the environment with no possibility of detection with naked eye at safe distances.These devices have devastating consequences such as loss of life or disability of military personnel, canine companions, civilians, sudden chaos and commotion, destruction of valuable supplies and equipment.

Figure 1.1: Remotely Controlled IED

[26]

Figure 1.2: Roadside Tiffin Box IED

Figure 1.3: IED's made using routine life utensils

1.1.1 Components of an IED

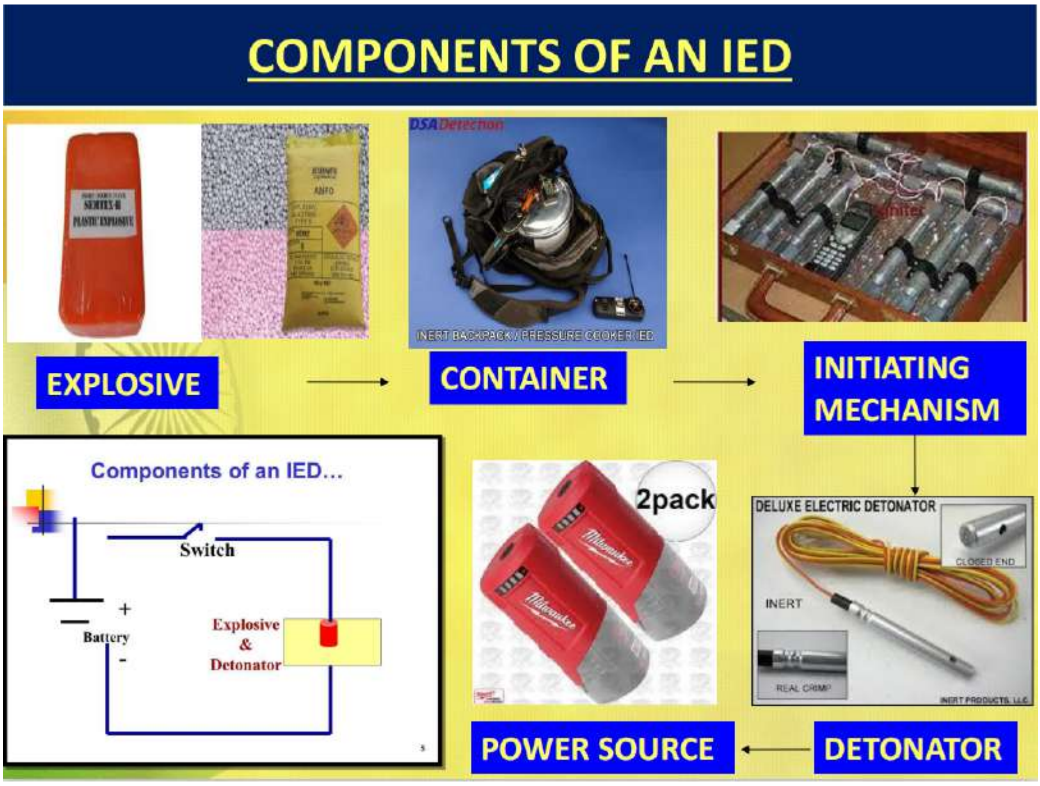


Figure 1.4: Basic Components of an IED

[24]

1. Power Source
2. Detonator
3. Initiating Mechanism
4. Container
5. Explosive/Lethal Projectiles(nails,ball bearings)

1.1.2 Types of IEDs

Based on the mechanism of detonation, IEDs are broadly classified into three categories:

1. **Victim Operated**: Victim operated are the most dangerous as they are concealed inside human clothing nearly impossible to detect and as worst case scenarios even in dead bodies these include suicide vests, vehicle rams, pressure plates etc.
2. **Command Activated**: This is a complicated IED often known as **RCIED** which can be detonated remotely by a controller which may be a command wire, cellular device

or any other equipment which could be operated via digital or analog signal from a safe distance.

3. **Time/Delay/Ambient**: The detonation of such type of IED is subject to environmental changes in time, temperature, light, sound, pressure, data values, magnetic influence and requires two stages of identification first being recognition as IED and second to vigilantly determine the environmental variable.

These three major classifications can further be subdivided on the basis of particular type of equipment and explosive used.

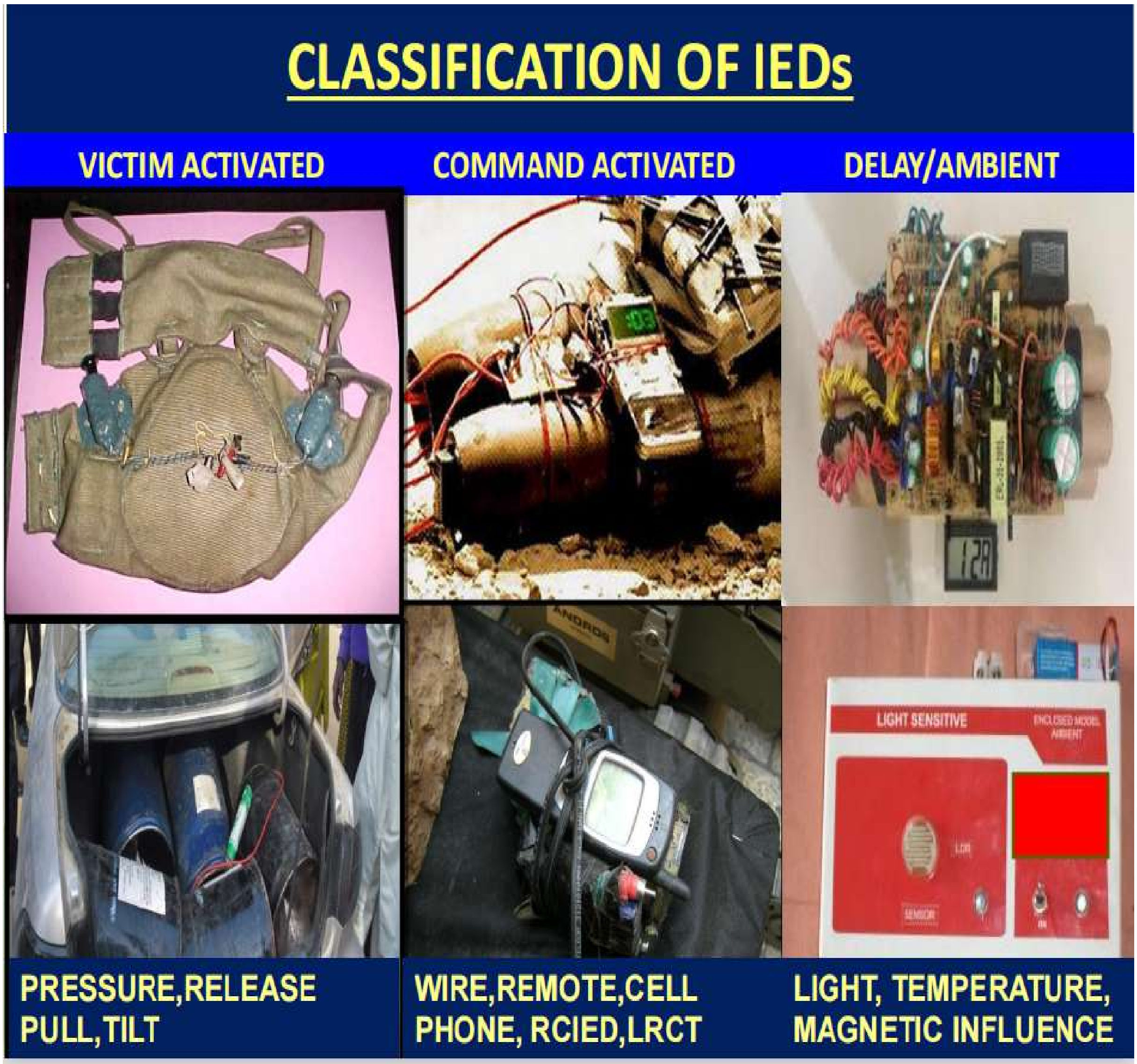


Figure 1.5: Broad Classification of IEDs

[18]

1.2 Explosive Ordnance Disposal(EOD)

Explosive Ordnance/IED Disposal is the global term regarding Counter-IED operations which include these conventional steps:

1. **Identification**: To identify and gather intelligence of the area of suspected IED.
2. **Marking**: Once the reconnaissance of the area is complete, the suspected IED area is minimized and marked by flags.
3. **Detection**: After marking, the expert personnel also known as EOD TECH along with his K9 sniffer dog and equipment moves towards the marked area to pinpoint the IED and also determine the type of mechanism and explosive used in it.
4. **Defusal and Disposal**: Once the detection is complete now it depends on the expert whether to defuse(cut the connection between initiating mechanism detonator and explosive and prevent explosion) or dispose off the IED as such inside the the bomb kettle to reduce its impact.

Figure 1.6: IED Area Identification and Reconnaissance

[25]

Figure 1.7: Area minimisation by marking flags

Figure 1.8: Detection by EOD expert using Metal, Explosive and Non-linear Junction Detector [25]

Figure 1.9: Area localisation by Sniffer Dogs/K9 units
[25]

Figure 1.10: Various Defusal and Disposal Techniques used in EOD
[25]

Figure 1.11: Disposal using Bomb Kettle
[25]

1.2.1 Detection Defusal and Disposal Techniques for different categories of IEDs

The detection techniques can be categorized for three types:

1. **Non-explosive Substances**: Non-explosive components like electronic circuits, detonators, triggering mechanisms etc.

    - X-ray Detection.
    - Non-linear Junction Detectors: which detects junction devices especially semiconductors, ICs which are common in electronic triggering circuits of IEDs.

Figure 1.12: Non-linear Junction Detector NR900-K
[25]

2. **Vapours or traces of Explosive Substances**: may be standard or improvised.

    - Vapour Detectors: Measure volatility of Explosive Substances and ratio of concentration of molecules to air in parts per trillion.

- Biological Detectors: Sniffer Dogs, Bees, Rats, Antibodies.
- Chemical/Electrochemical Methods: Spectroscopy, Chromatography, Redox Reactions.

3. **Bulk Explosive Substances**: The main explosive charge.
   - X-ray Detection: Tomography.
   - Electromagnetic Methods: Magnetic Resonance, Subsurface RADARS.
   - Nuclear/Non-nuclear Methods: Neutron Analysis, Radiography, Acoustics, IR.

1.2.2 Technological Advancements in EOD

Previously the IED's were handled manually by EOD experts, the advantage of which was taken by miscreants/terrorists as they would then especially target EOD teams itself by setting sensitive traps within IED's resulting into loss of life. Thus global organizations against terrorism preferred and directed militaries to handle IED's remotely which led to development of EOD robots, which were the modified version of battle tanks reduced in size, varied payload and already existing unmanned vehicles used for archaeological excavations.After a decade of research Lt. Col. Peter Miller of British Army's Tank Regiment was the first one to deliver a fully functional EOD robot named **WHEELBARROW ROBOT** in 1972 during Irish War by modifying a lawnmower, further research was carried on his fundamental robot and modified accordingly, the design of this bot is still preferred worldwide irrespective of technological advancements.Similarly DARPA(Defense Advanced Research Project Agency) of USA has developed many designs for EOD as well. India's Defense Research and Development Organisation(DRDO) has designed and inducted a CBRN(Chemical, Biological, Radiological and Nuclear) environment robot named **DAKSH** with help of Dynalog Inc. Also Indian Army's engineers have developed a bot named **Xploder**, which has a self destruct option along with other required features as a contingency plan fighting Terrorism in Kashmir and Naxalism in Chattisgarh. These are the few of many designs available and under development round the globe.[2][19][23]

Apart from induction and usage of unmanned robots for this purpose even infantry vehicles were modified leading to development of **Minesweepers** and **Mine Resistant Ambush Protected(MRAP)** vehicles for the military.

Figure 1.13: DRDO DAKSH ROV

Figure 1.14: Minesweeper Tank

Figure 1.15: Mine Resistant Ambush Protected Vehicle

1.3 Need for an Enhanced Model

Conventional EOD robots have certain limitations:

- Currently existing bots have either wheeled chassis or full caterpillar tracks, which limit the bot's capability of all-terrain mobility.
- The manipulator has only 2 degrees of freedom on EOD bots which limits it range of motion.
- Most EOD robots don't have on-board sensors and necessary equipment like jammers.
- Conventional designs have limited power supply.

1.4 Objectives

Our main objective to enhance the design and technology of the currently existing EOD robot models. We plan to include certain modifications into our design as listed below:

- Quad Track Drive Chassis with Independent Caterpillar Track and Belt-Link Sprocket Suspension.[6]
- EMP(Electromagnetic Pulse with microwave isolator)
- ESD(Electrostatic Discharge Protection by Faraday Caging)

- Jammers(Cell Splitting technique for distribution of high transmission power among multiple antennas)
- FLIR/Thermal/Night Vision(RF vision)
- Manipulator design with 6 degrees of freedom(for defusal and disposal operations)
- Detachable Manipulator
- Hydraulic Piston Mechanism
- Self Concealing APU(Self Concealing Design for auxiliary power unit)
- Layered/Stacked MPU(Layered Battery Design for main power unit)
- Passive Mobile Switching Bay

1.5 Applications

Our proposed design is itself based on enhancements in the currently existing technologies with some minor changes in equipment payload some of the fields in which our proposed design would prove to be an efficient aid are:

- Nuclear Plant Maintenance
- Space Exploration
- Archaeological Excavation
- Military Reconnaissance
- Underwater Exploration
- Amphibious Operations
- Rescue operations
- Biomedical Designs
- Automobile Designs

1.6 Motivation

- Loss of lives of military personnel and dogs like tragic incidence during 2016 Pathankot attacks , we lost two officers of the EOD team of Indian Army due to a CWIED.

- Vehicle based IED attack of Pulwama 2019 in which we lost 44 personnel.
- Routine IED attacks on CRPF posted in Chattisgarh by Naxalites.
- The development of synthetic chemicals has increased production of powerful explosives.
- Most of the time, material with a doubtful origin is manipulated by specially trained bomb squads.
- Since the explosive is prepared for the highest damage , complicated and even remotely controlled triggering mechanisms challenge a specialist's talents.
- The basic reason and justification of the need for an EOD robot is simply the fact that it saves human life in an explosion.
- The robot can be operated meters away from the danger zone, providing a totally safe place for explosive specialists.
- In addition, these robots can be used not only for disarming the explosive ordnance but also collecting information about the threatening material and the area before human interference.

1.7 LITERATURE SURVEY

1.7.1 Detection of Improvised Explosives and IEDs by A.V. Kuznetsov, O.I. Osetrov

In this paper an overview of Detection techniques for IEs and IEDs is given, by the help of which we have recognized the ways by which it can be accommodated and improved by a robot, like a single RF feed camera with inbuilt FLIR(Foward Looking Infra Red), Thermal and Night Vision, Manipulator with varied accessories of Vapour Detector, XRay Scanner Module and Metal Detector. It also helped us to eradicate the use of NLJD by incorporating EMP circuit.[11]

1.7.2 Disposal of IEs/IEDs by Hitlmar Schubert

From this paper we have acquired the knowledge about Disposal of IE/IEDs respective to the certain Components, Types of IED and also the environment in which it is planted.Previously for disposing RCIED a separate jammer module had to be carried and placed near the suspected

IED, we have eradicated the extra effort by incorporating Onboard Jammer, our manipulator gripper design is capable of both defusing and disposing the IED into a bomb kettle on the spot without any certain requirement.[19]

1.7.3 Military Robotics: Latest Trends and Spatial Grasp Solutions by Peter Simon Sapaty

In this paper we were educated on the concepts of Spatial Grasp Technology which can be applied to both manned and unmanned systems and its advent into defense sector, which helps in integration and coordination of various distributed systems thus paving the way of autonomous EOD bots in our case.[21]

1.7.4 Design Analysis of a Remote Controlled Robotic Vehicle by B.O. Omijeh

In this paper the design of a Remote Controlled Robotic Vehicle has been designed and analysed which helped us in studying the various basic parameters required for making a remotely controlled bot especially for handling hazardous materials such as ours wihtout any onground technical support.[16]

1.7.5 Low-Cost Explosive Ordnance Disposal Robot for Deployment in Southeast Asia by Matthew Fracchia

This paper has provided us with the idea of field of vision of a bot(POV) and also how to make it cost effective as it significantly resembled our notion.The authors have used two cameras one at claw and other at chassis end which helped us designing God's Point of View for our bot.[5]

1.7.6 Self Controlled Robot For Military Purpose by Mithileysh Sathiyanarayanan

In this paper authors have worked towards the concept of autonomous robots in the military this has helped us in the integration of various sensors on board the robot and transfer of sensor data from bot to base. [17]

1.7.7 Application of Radio Frequency Controlled Intelligent Military Robot in Defense by Saradindu Naskar

In this paper the authors have elaborated the extensive varied use of Radio Frequency in tactical environment. This concept helped us in setting up the full and half duplex communication between our bot and base station. [14]

1.7.8 Kinematics of Soft Robots by Geometric Computing by G. Fang

This paper gives us the idea of Kinematics of different materials under different movements and stresses, which has helped us in choosing the material for designing our bot especially the Manipulator with 6 degrees of freedom.[4]

1.7.9 Kinematic Synthesis of a Serial Robotic Manipulator by Using Generalized Differential Inverse Kinematics by S. Shirafuji

In this paper the authors have shown an easy way of calculating the trajectory of manipulator motion by using Differential Inverse Kinematics which has greatly helped in designing our Manipulator with 6 degrees of freedom for a pick and place operation.[20]

1.7.10 The Impact of Transmission Power on the Performance of MANET Routing Protocols by V. Lalitha

This paper discusses the impact of varied transmission power of nodes in a Mobile Ad-Hoc Network, which has helped us in designing a case study for our Onboard Jammer design based on Cell splitting Technique.[12]

1.7.11 Simulation of Barrage-Type Jamming for Synthetic Aperture Radars by Hongfeng Zhao

In this paper the authors have a simulation case study for barrage type jamming which leads to full spectrum jamming , which has helped us to study and work towards frequency selective jamming model for our Onboard jammer especially 450-900 Mhz.[27]

CHAPTER 2

DESIGN AND ARCHITECTURE OF ENHANCED EOD ROBOT

The figures Fig 2.2 and 2.3 provide a system design and methodology overview, that is, the **System Architecture** and **Mechanism** of our robot.

As shown in Fig 2.2, the communication between base/control station and robot is maintained by **Radio Frequency** channel with both types of tranmsission and recpetion modes:**Full Duplex**: for sensor data and feedback.**Half Duplex**: for actuation of motors, pistons, jammer and emp circuits.These functions of the robot would be controlled by a custom PCB designed **motherboard**, along with other circuits like motor driver, jammer, emp(marx generator/high voltage converter circuit), circuit for battery management system etc.Unlike conventional **caterpillar tracks**[15] we have designed a completely new set of tracks which would be rotated by **DC motors**, while the joints of the **manipulator** by **Servo Motors**.For power we have gone with a foolproof tactical design of **Main and Auxiliary Power Unit** and the chassis body will itself act as an **Electronics Cabinet**.[7]

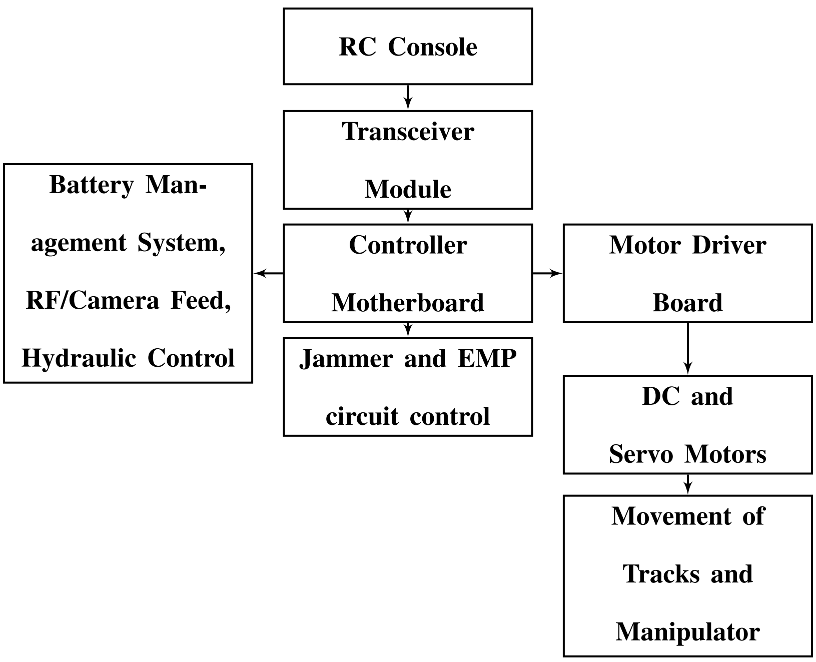


Figure 2.1: Overall Framework

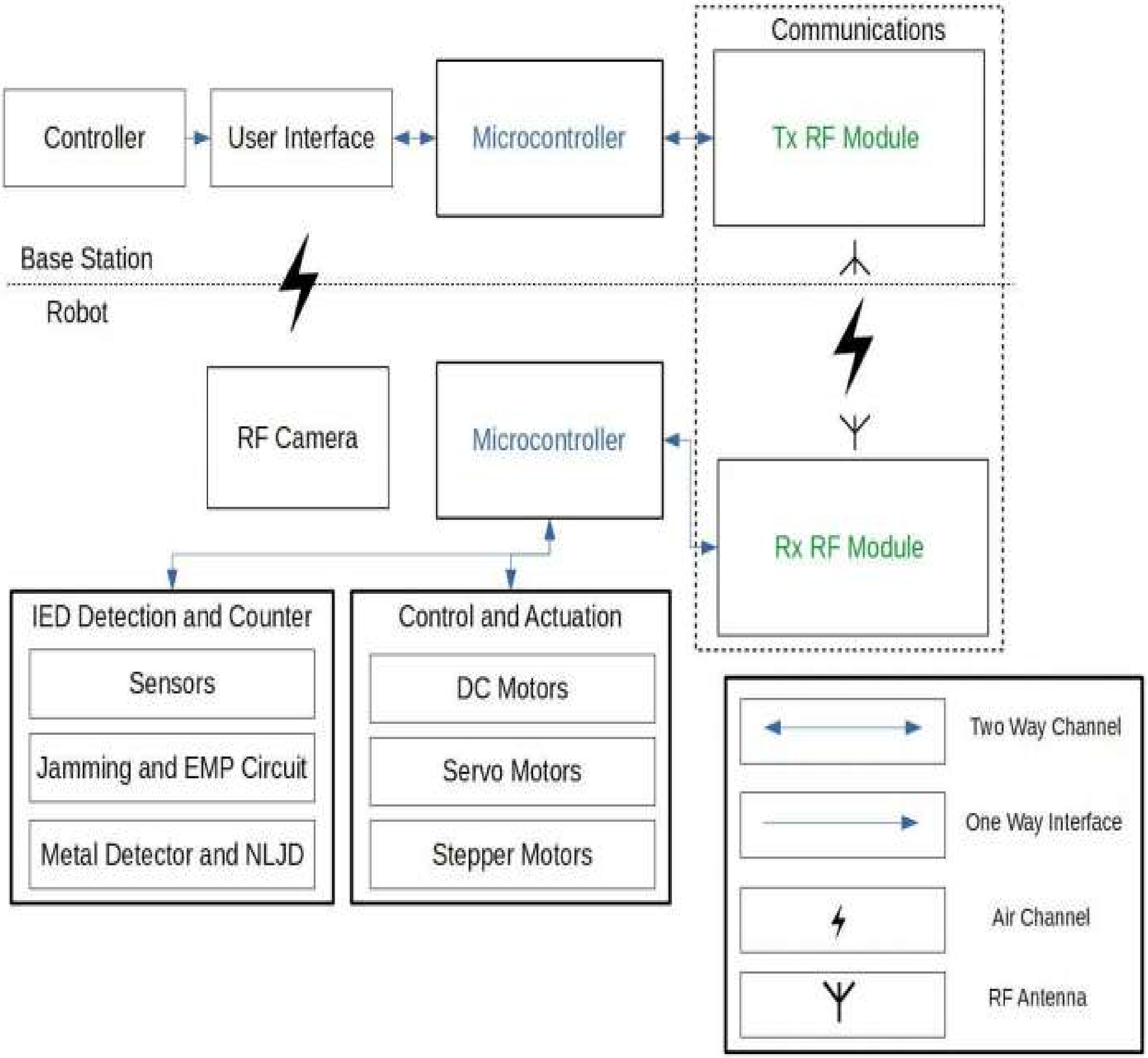


Figure 2.2: System Integrated Design(Control System Architecture)

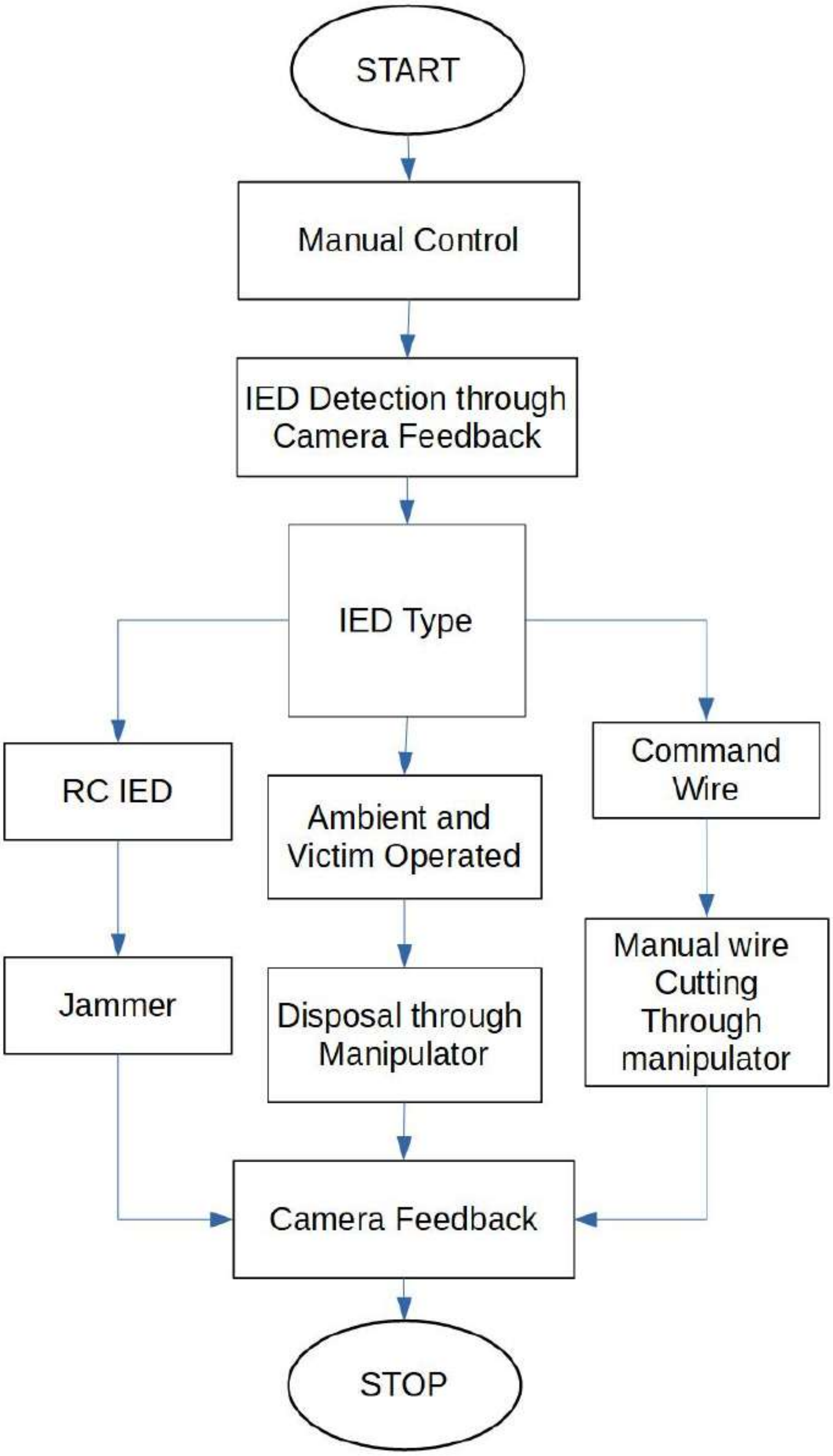


Figure 2.3: Conceptual Flowchart(Robot Mechanism Algorithm)

2.1 Kinematic Analysis

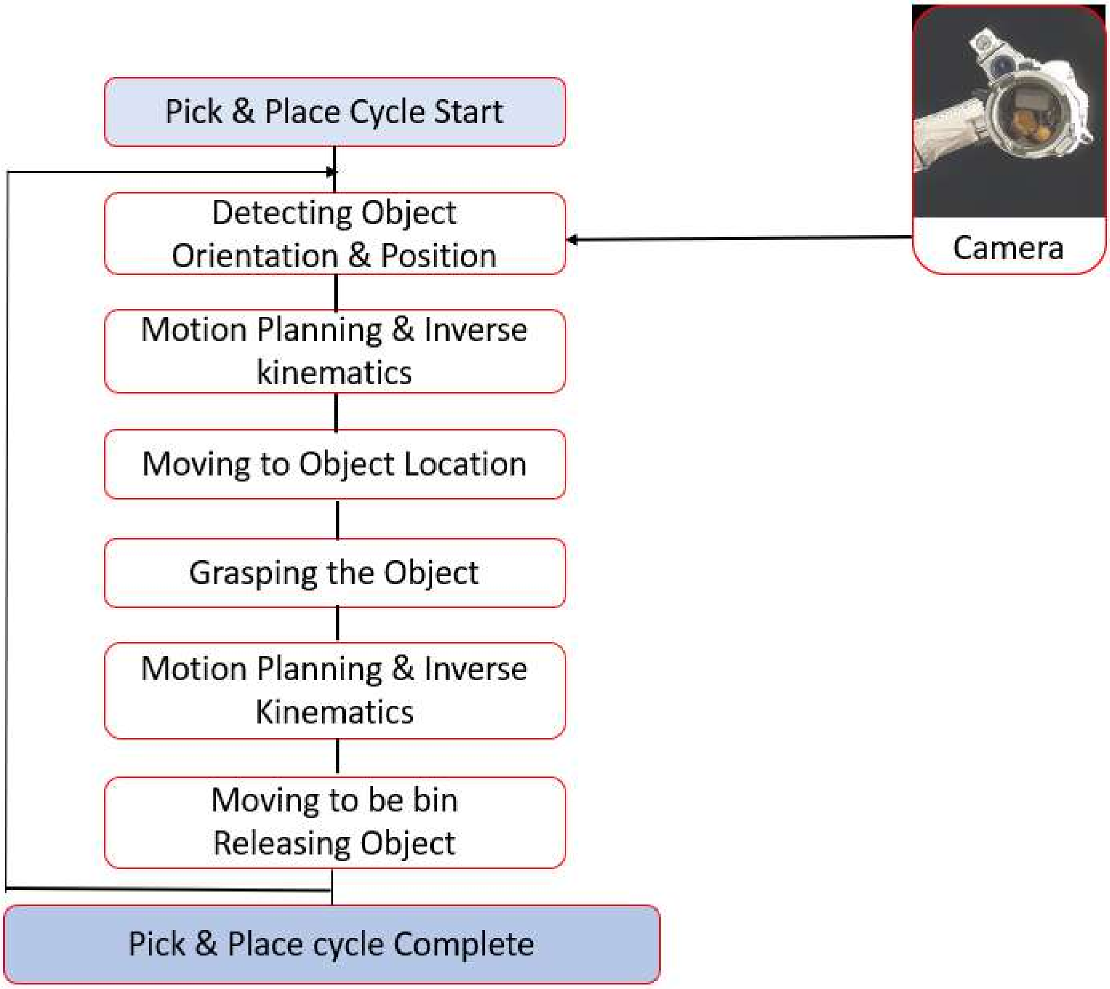


Figure 2.4: Arm Mechanism Algorithm

2.1.1 Forward Kinematics

In FK problem, we know all the joint variables, that is the generalized coordinates associated with the joints, and we wish to calculate the pose of the end effector in a 3D world. It is solved by the method of homogeneous transforms in which two reference frames are both simultaneously rotated and translated with respect to each other. In forward kinematics we use composition of homogeneous transforms. We start with the base link and move link by link to the end effector.

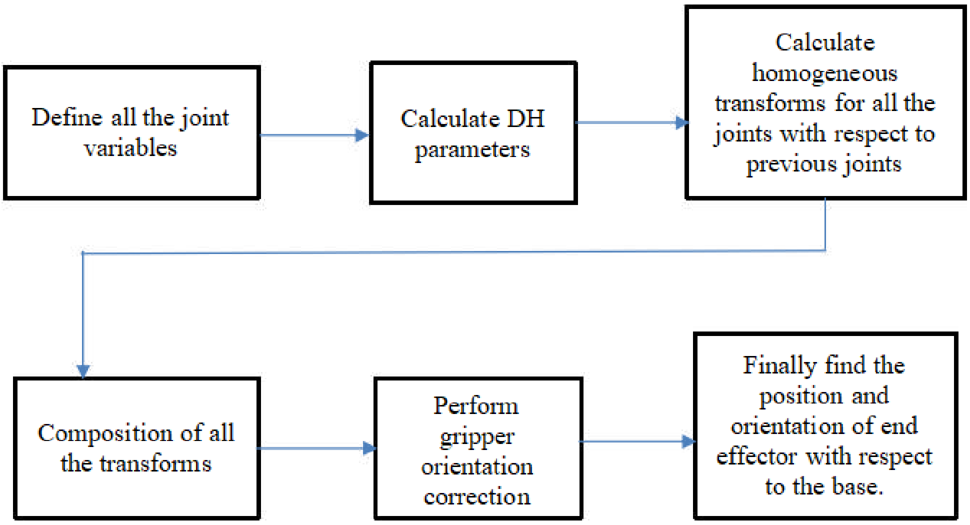


Figure 2.5: Forward Kinematics Flowchart

2.1.2 Inverse Kinematics

Inverse kinematics is the opposite of forwards kinematics. In this case, the pose (i.e., position and orientation) of the end effector is known and the goal is to calculate the joint angles of the manipulator. However, the IK problem is significantly more challenging. It involves calculation of 6 joint angles which is comparatively more complex.

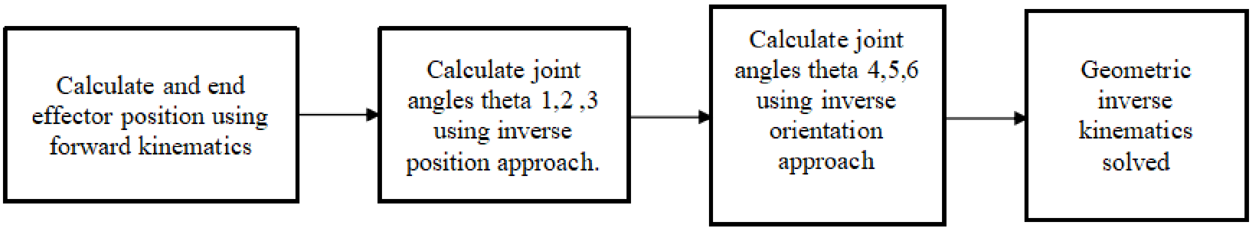


Figure 2.6: Inverse Kinematics Flowchart

2.2 Conceptual Sketches using CAD

We have designed our robot's chassis, tracks, suspension in **Autodesk Fusion 360** and manipulator arm in **DS Solidworks**.

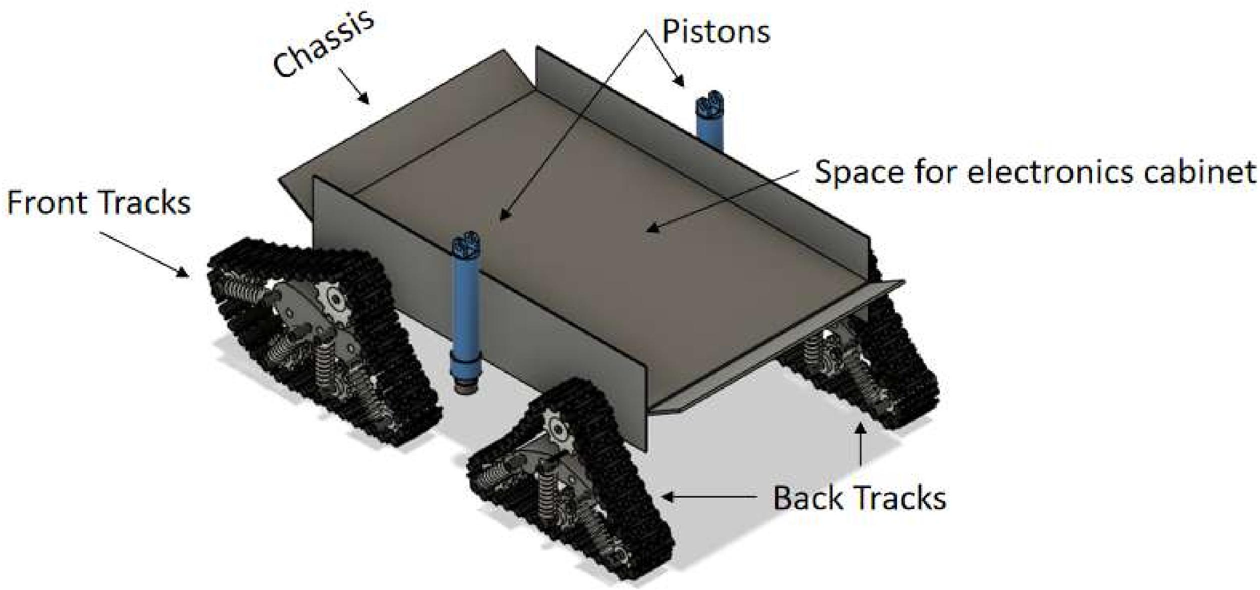


Figure 2.7: Isometric View of complete Chassis design without manipulator arm

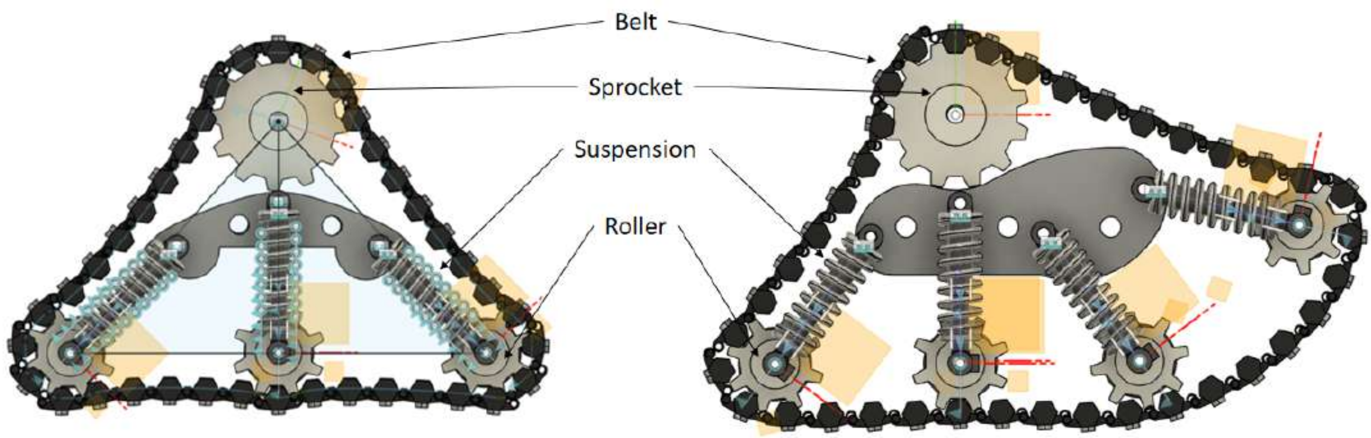


Figure 2.8: Back and Front Track

Figure 2.9: Elemental Parts

This is the novel design of our robot chassis which includes:

1. **Quad Caterpillar Tracks with independent drive mechanism**
2. **Belt link Caterpillar Track**
3. **Sprocket and Roller Suspension**

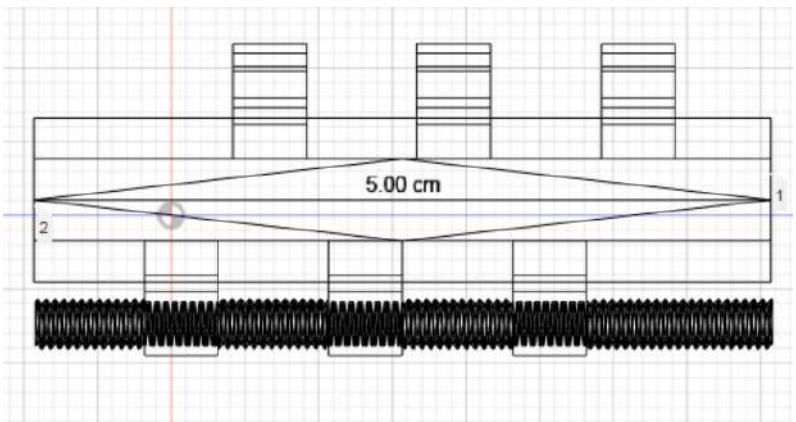


Figure 2.10: Belt Link Dimension

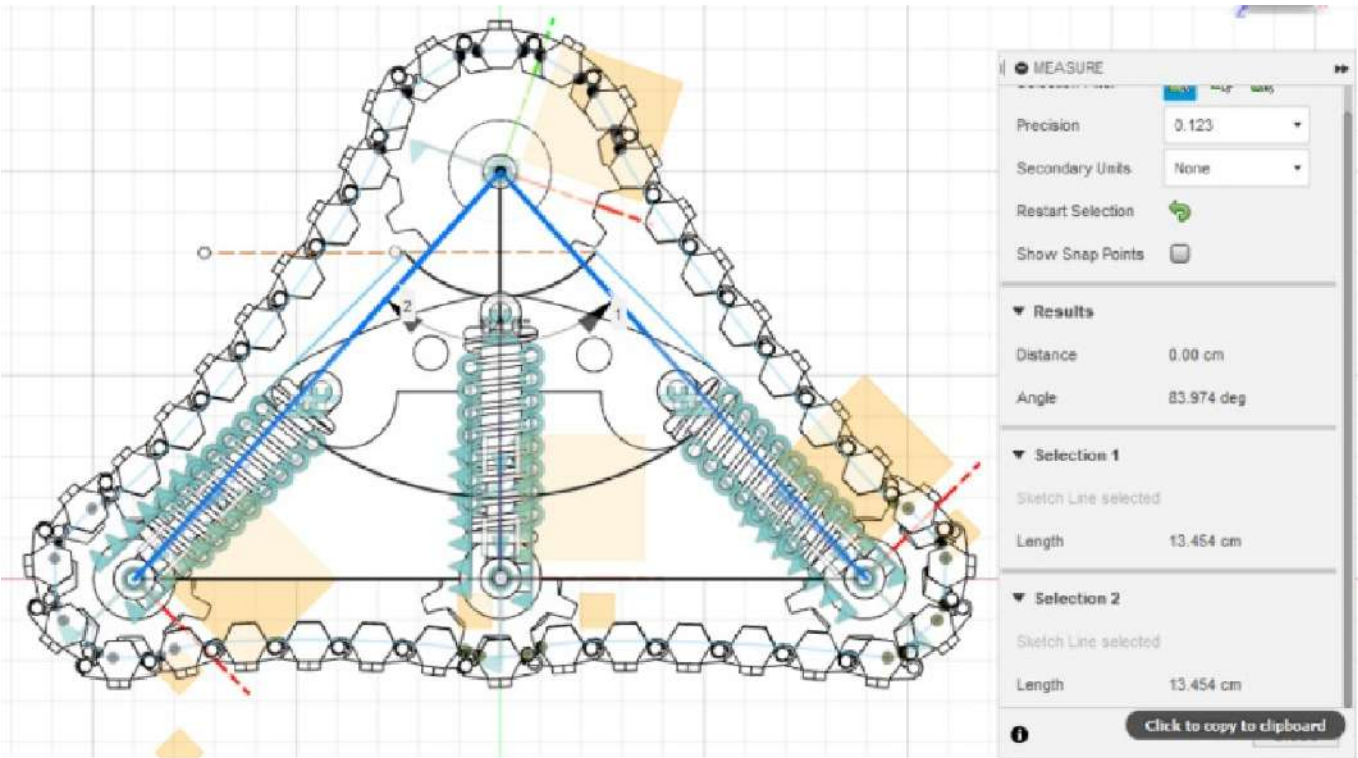


Figure 2.11: Back Track Dimension

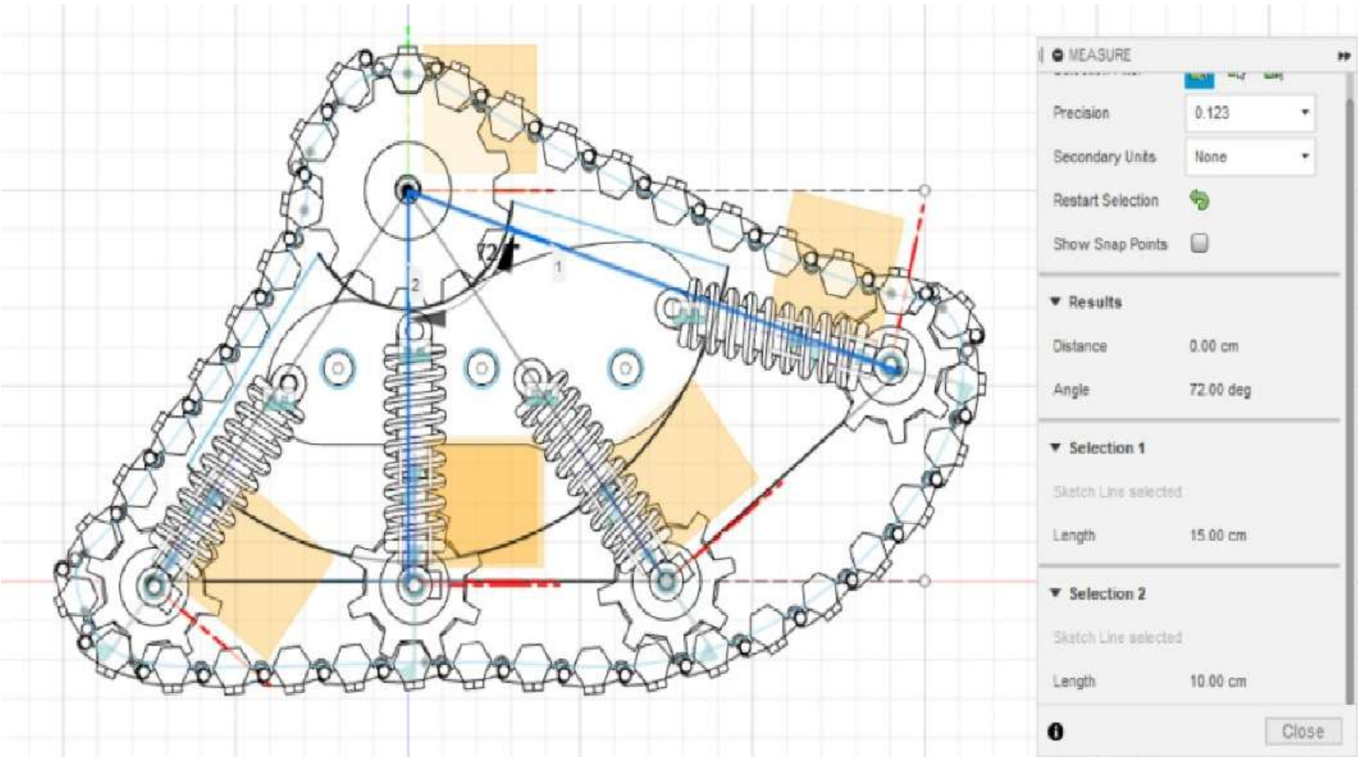


Figure 2.12: Front Track Dimension

Part	Motion	Dimension
Chassis Base-plate	Fixed	45cm * 30cm*0.3cm
Chassis Side-plate	Fixed	45cm*5cm*0.2cm 30cm*5cm*0.2cm
Belt Link	Path Following	5cm length
Sprocket	Rotation	6cm diameter 3.5cm height 0.5cm gear width
Roller	Rotation	4cm diameter 3.5cm gear height 0.5cm gear width
Suspension Piston	Extension/Compression	2.5cm clearance 5cm height
Suspension Spring	Extension Compression	0.3cm section size 1.5cm diameter 9 revolutions 5cm height
Back Track	Path Following	10cm sprocket to mid roller 13.5cm sprocket to secondary rollers 83.4° angle
Front Track	Path Following	10cm sprocket to mid roller 13.5cm sprocket to secondary rollers 83.4° angle 15cm sprocket to front roller

Figure 2.13: Chassis Component Dimensions

These above designs are of the complete chassis base-plate, side-plate, caterpillar tracks and suspension.

Unlike conventional caterpillar tracks, which comprise two layers of padding over sprocket and rollers, our track belts are made by chain pattern of **single Hexagonal Belt Link with outer spike**, which eradicates the use of usage of two layers. Hexagonal design is reliable also the rollers have **gear tooth** for feasible motion and interlocking of belt link into them.[9][10][13]

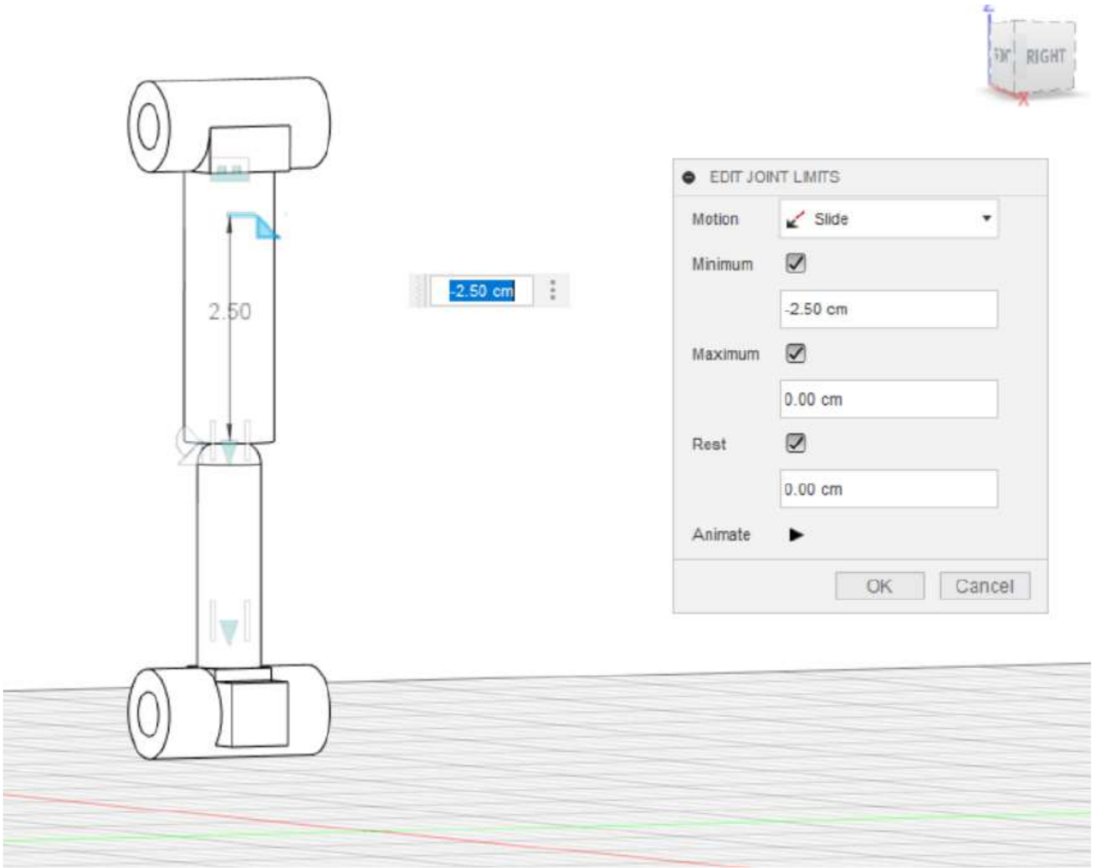


Figure 2.14: Suspension Piston Slider Limits

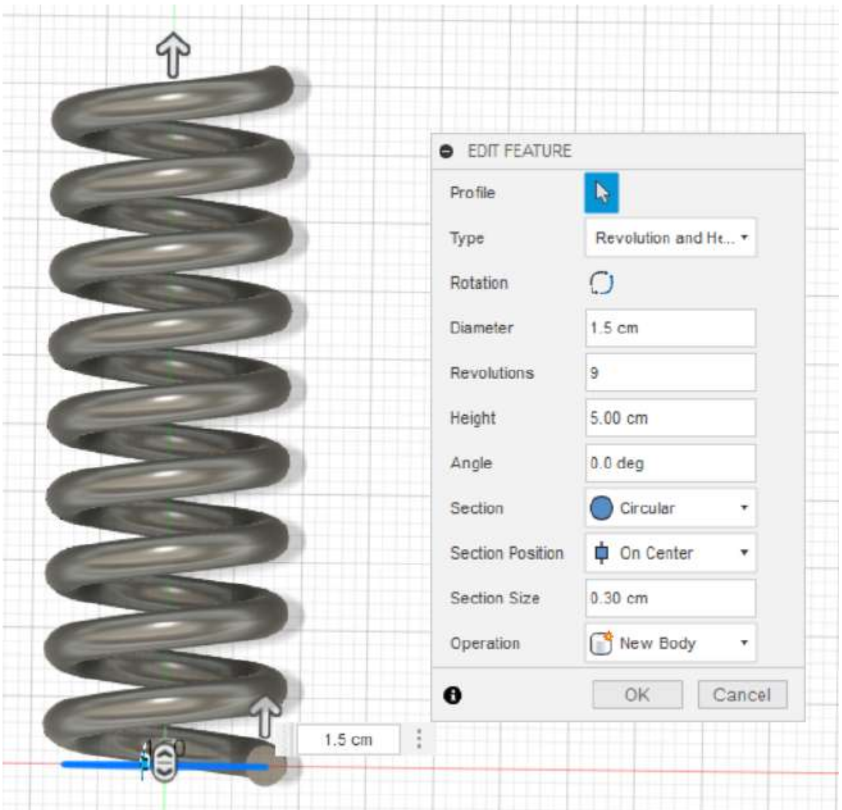


Figure 2.15: Suspension Spring Specifications

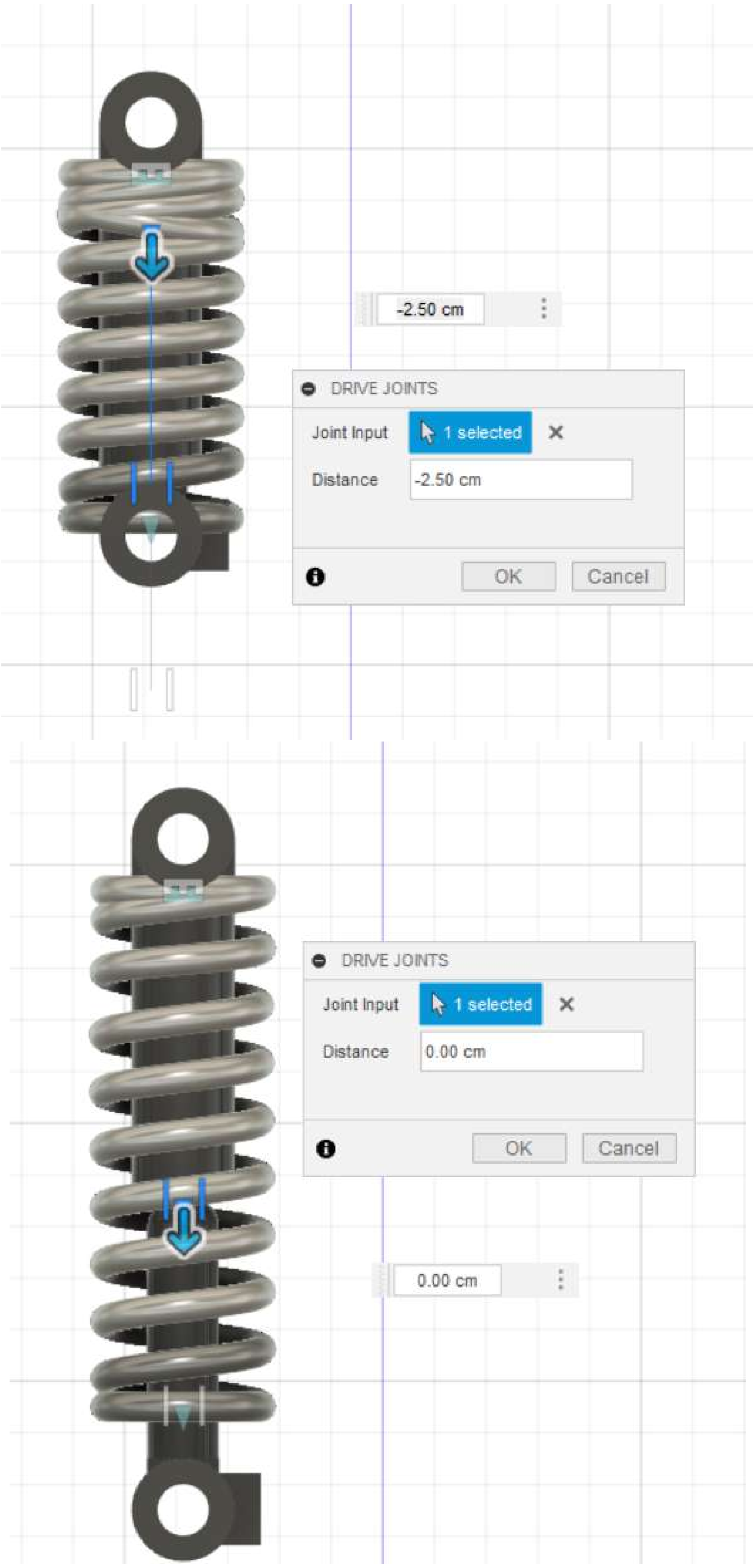


Figure 2.16: Compressed and Relaxed Suspension

The whole track is rotated by **Driver Sprocket**, which is itself driven by **DC motor** shaft.The suspension is itself a **shock absorber** which helps in obstacle clearance.The front track has a **protruded roller design** for steep obstacle clearance. The front and back track assemblies are attached to chassis side plate mounts. The **ground clearance** of bot is *15cm*, also equipped with **hydraulic piston** to aid the robot's motion in swamp terrain by increasing the ground clearance by another *10cm*.

The chassis is designed to itself act as an **electronics cabinet** which houses the electronic circuits and also protect them form electromagnetic disturbances.

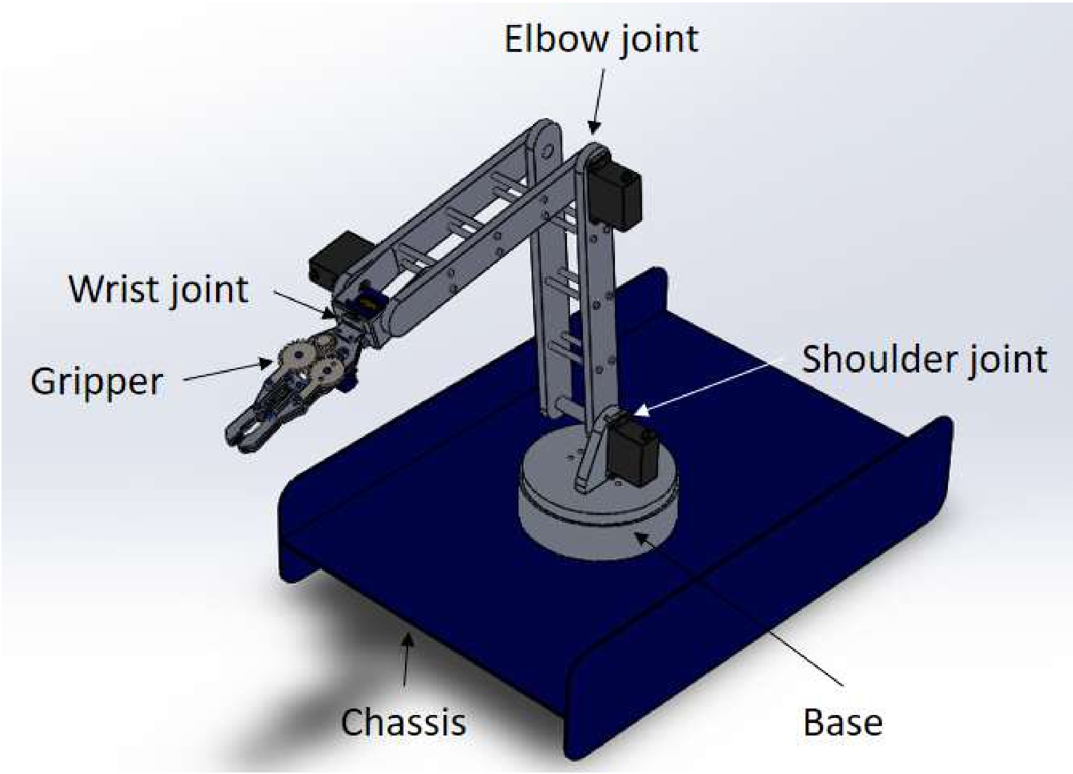


Figure 2.17: Isometric View of complete manipulator arm design mounted on Chassis body

The purpose of manipulator arm mounted on the chassis is mainly to **defuse or dispose off the IED**. The arm is analogous to human arm with **6 Degrees of Freedom**.The base revolves at *360°*, the base and shoulder joint resembles the ball and socket joint of human shoulder, then the elbow joint to wrist.

The wrist is also similar to human wrist, with **pitch, yaw and roll** movements.Each joint is controlled by **Servo Motor**.

Manipulator Component	Motion	Dimension	Torque
Base	Rotation(swoop)	80*100*50 mm	0.36 kg-cm
Shoulder	Swivel (up and down)	250*250*80 mm	1.75 kg-cm
Elbow to Shoulder Joint	Swivel (up and down)	200*200*80 mm	1.60 kg-cm
Elbow	Extension	50*60*20 mm	1.62 kg-cm
Wrist	Pitch and Yaw	36*50*280 mm	0.6 kg-cm
Gripper Joints	Linear	12*25*68 mm	0.14 kg-cm

Figure 2.18: Manipulator Component Dimensions

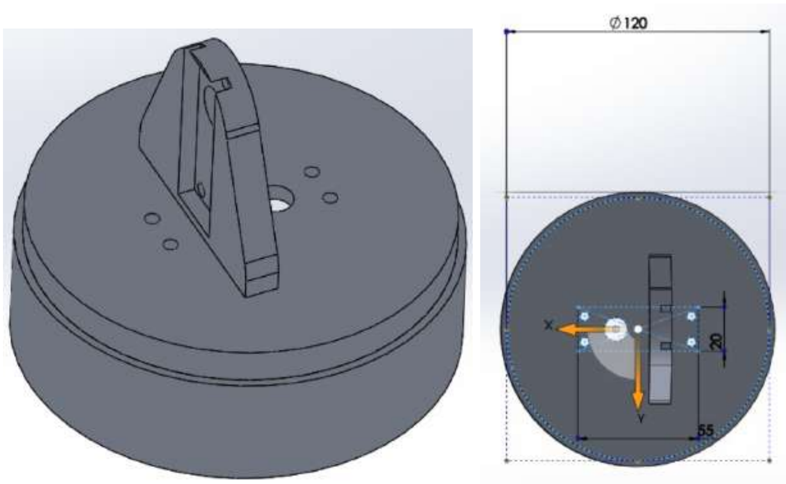


Figure 2.19: Manipulator base with shoulder joint

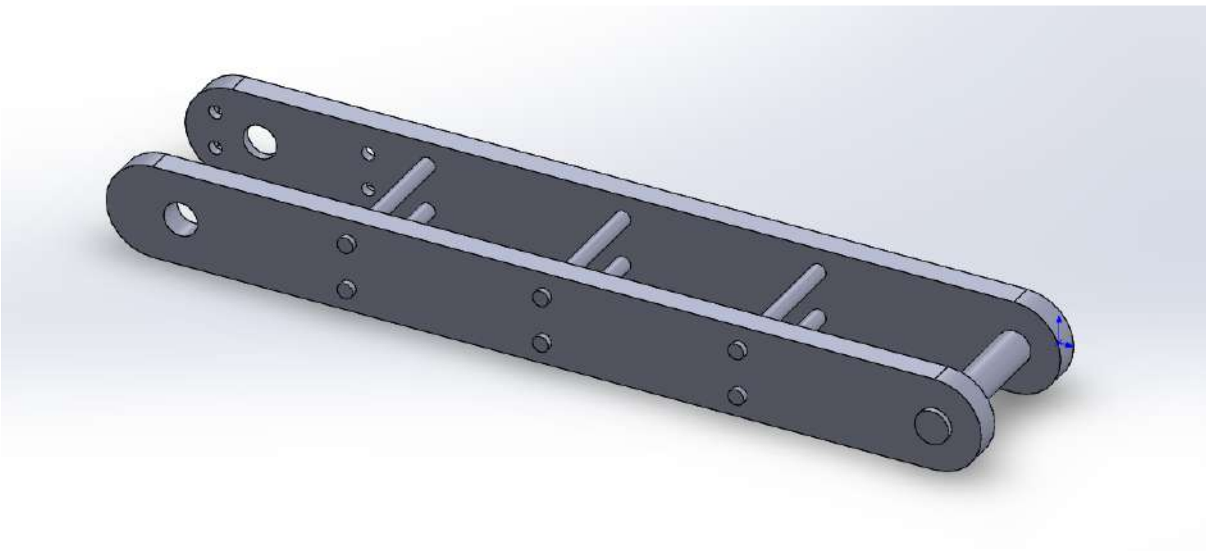


Figure 2.20: Shoulder to Elbow Component

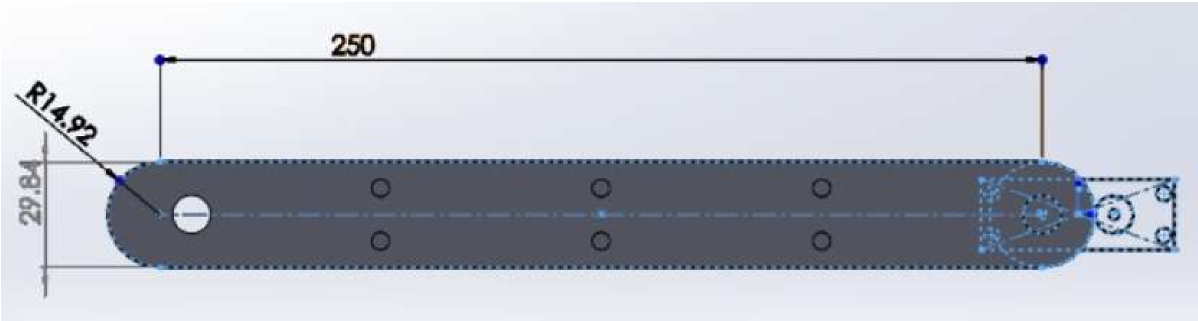


Figure 2.21: Shoulder Component Dimensions

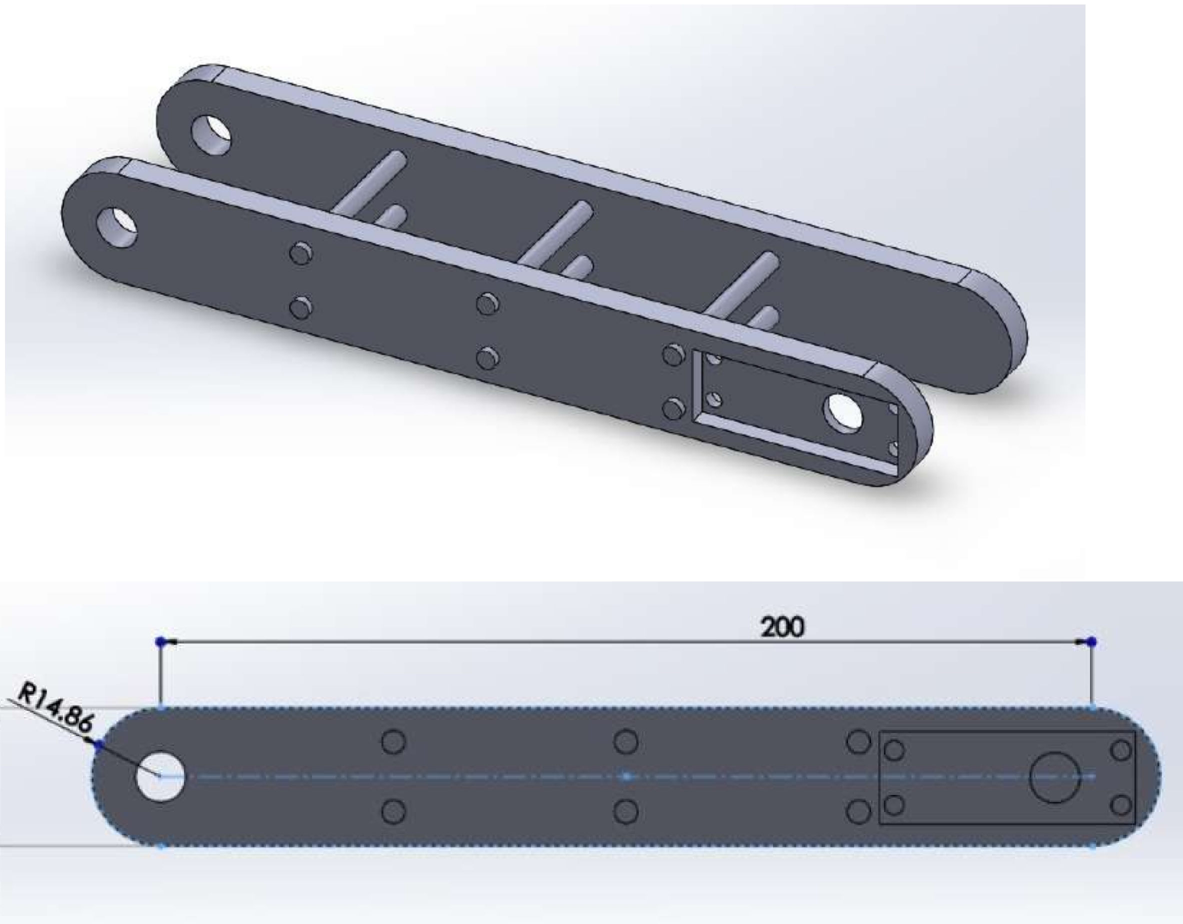


Figure 2.22: Elbow to Wrist component

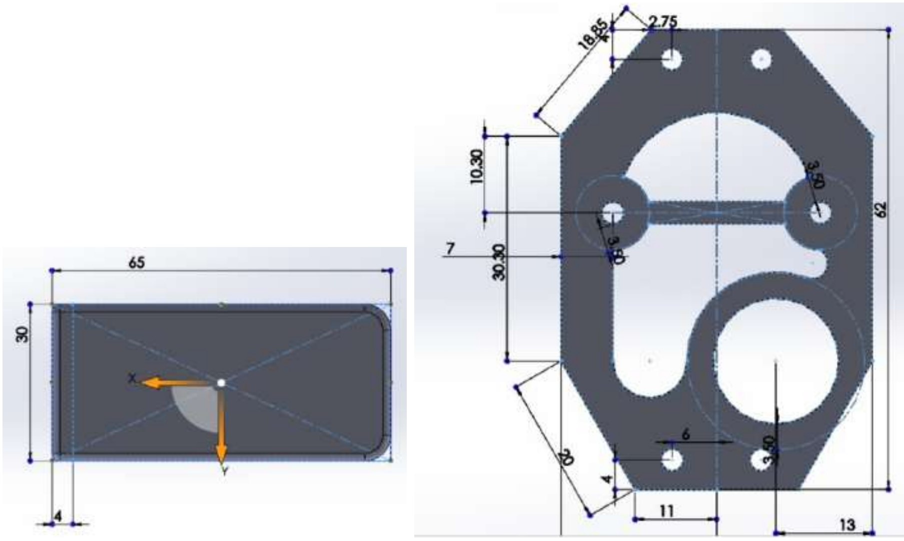


Figure 2.23: Wrist Gripper Mount and Mould

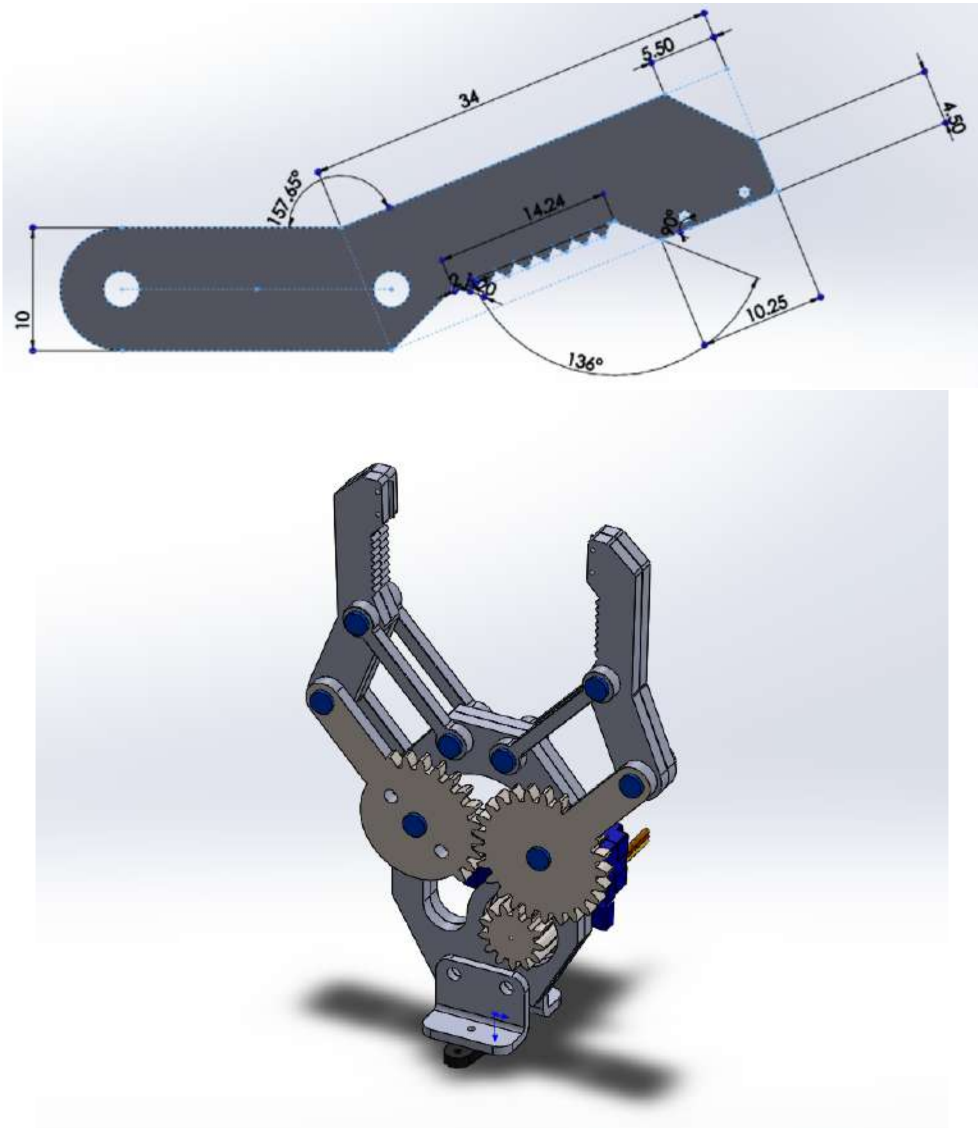


Figure 2.24: Gripper Pincer dimensions

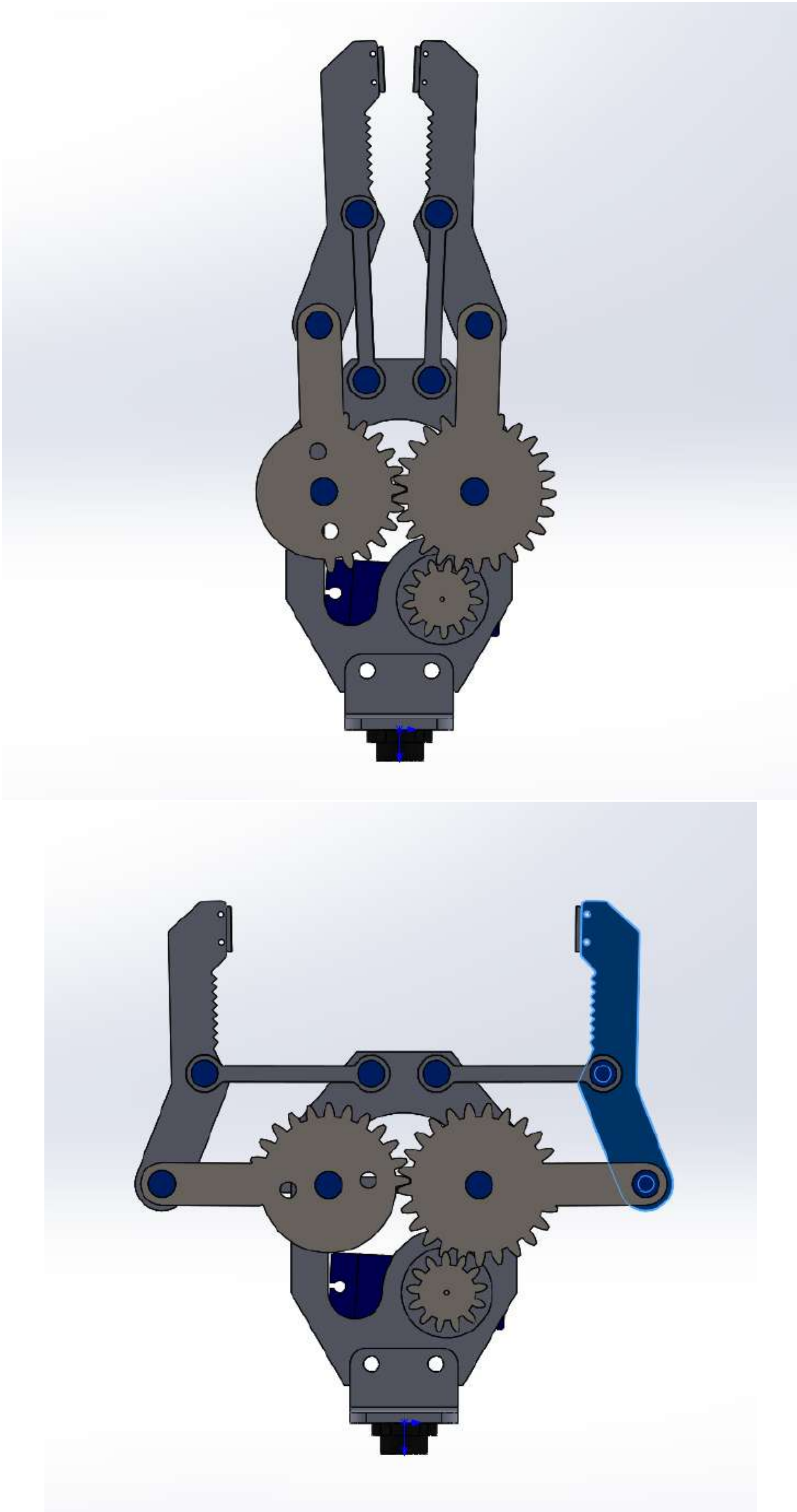


Figure 2.25: Contraction and Retraction of Manipulator Gripper

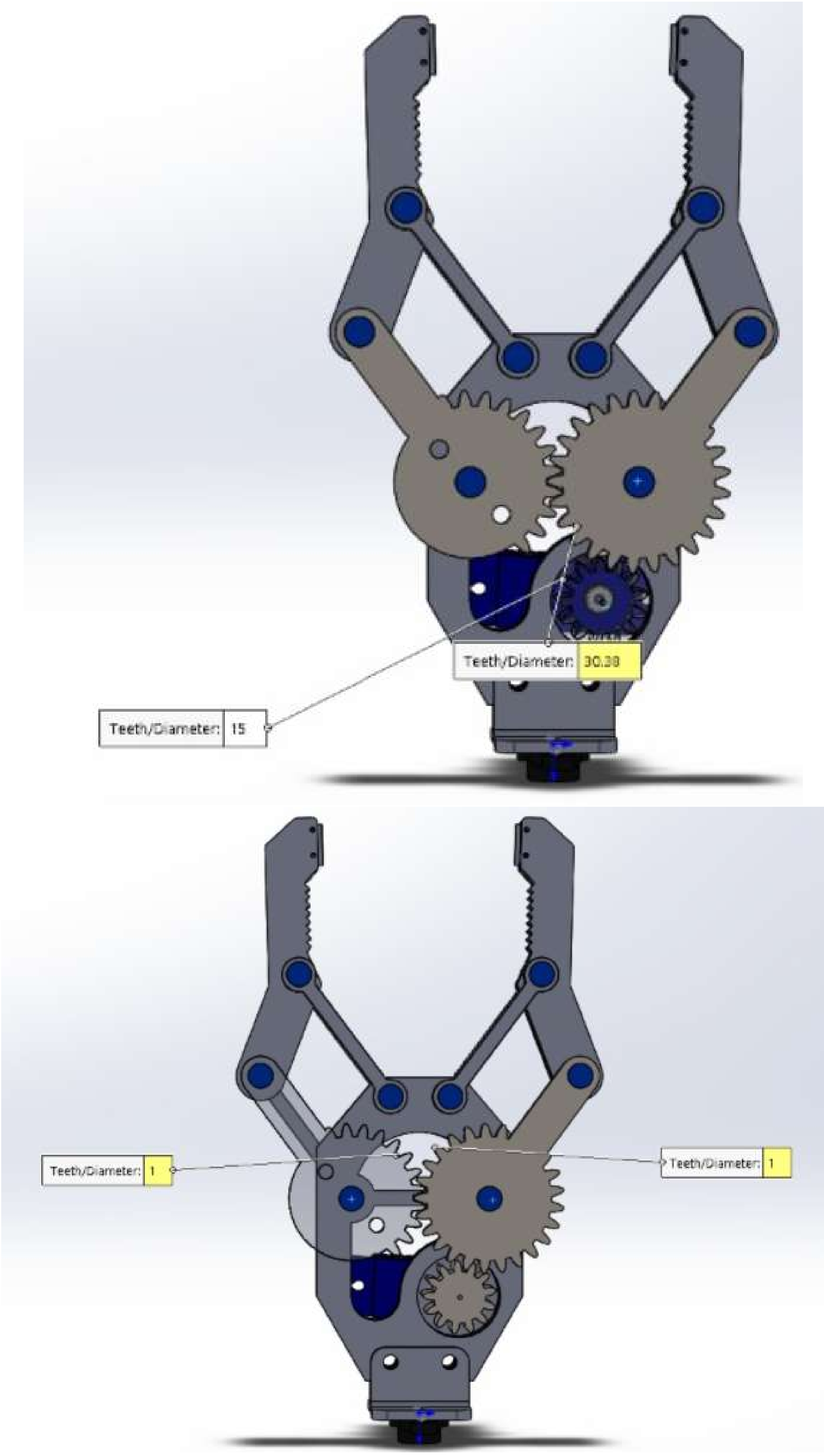


Figure 2.26: Gripper Pincer and Driver gear ratios

Figure 2.27: Manipulator Extension Motion

The gripper has a **Bladed Pincer** design which would suffice the purpose of defusal as well as disposal, driven by driver and pincer gears.

The skeleton is **laddered** which is a reinforced, sturdy design. The manipulator has a total **segmented length** of *52cm* with a reach of *32cm* ahead of chassis body.

The manipulator would be mounted with a RF feed camera with Night Vision and Forward Looking Infra-Red, also with other sensors like Metal Detector, Vapour Detector, X-Ray module, Ground Penetrating Radar, Magnetic Resonance Module.

Electromagnetic Shielding is mainly done to protect, electronic components from Electromagnetic Interference (EMI), which might disturb the ideal functioning of a component. It's principle is almost similar to that of electrostatic discharge and that's why a Faraday Cage structure is still the most feasible and efficient shield against EM disturbance. Our bot's structure is also designed keeping the same in mind, we have designed a chassis which itself is an electronic cabinet comprising base and upper plate of dimensions (45*30*0.3 cm) and side plates of dimension (45*5*0.2 cm). The thickness of these plates varies from 0.2 to 0.3 cm so as to just suffice the purpose of shielding and not block the communication between the control station and bot.

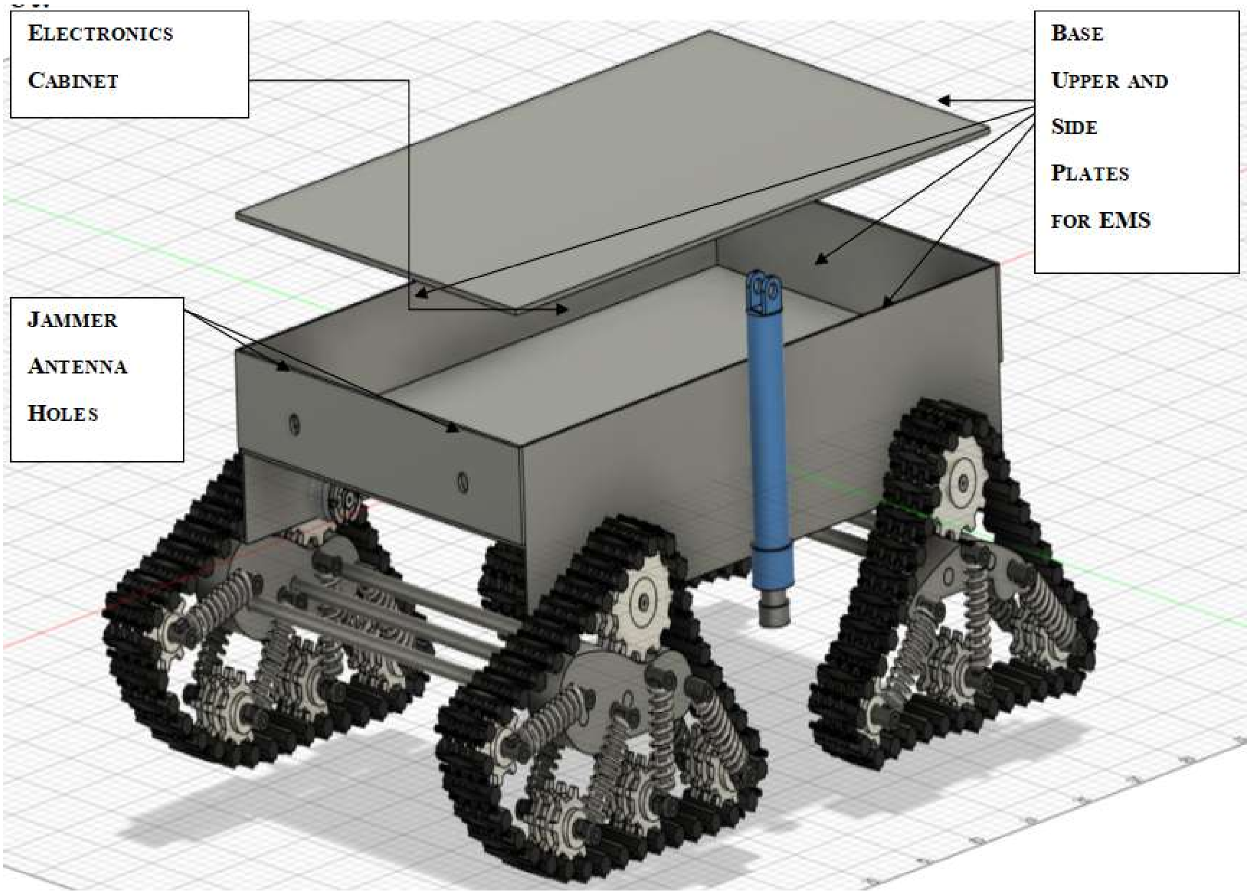


Figure 2.28: Chassis Electronic Cabinet Shielding

2.3 Control and Communication

Fig 2.2 aptly depicts the control and communication system architecture of our robot.Our bot is controlled remotely using **Radio Frequency** with the help of micro-controller and radio frequency module **nRF24L01** which operates on 2.4GHz ISM Band. The task is to take user input from a gaming console and use that data to control the robot's movement. The controller used here is Logitech f310 gamepad. It has two analog inputs and rest digital push buttons. The data from the controller can be taken by using the library "pygame".By using "pygame" module we are taking the input values from the controller. The input is taken in the form of an array of 17 elements.Now the controller has two analog joysticks which send a value of -10 to 10 to the computer, other than this the push buttons are used to send either 1 or 0. From 17 elements for the array four are dedicated for analog inputs and the rest for push buttons.

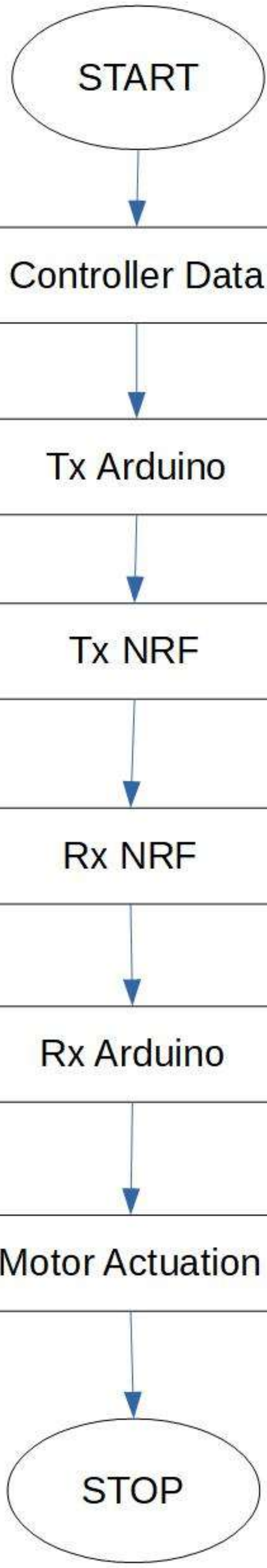


Figure 2.29: Control System Algorithm

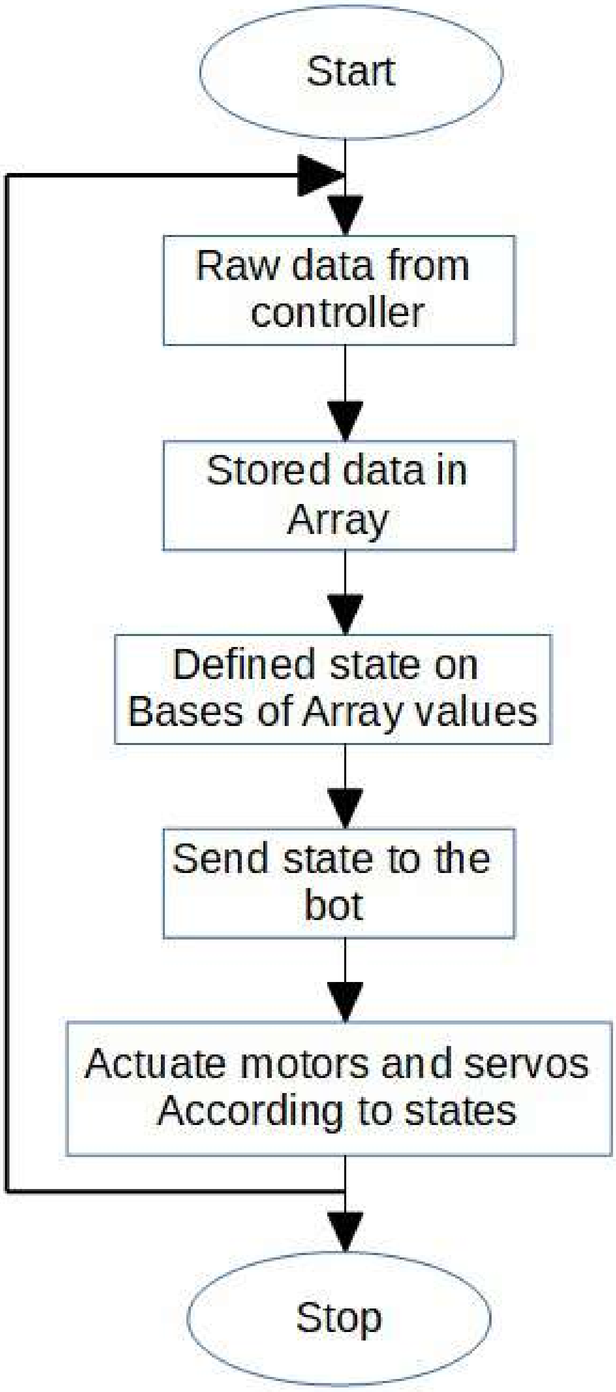


Figure 2.30: Communication System Algorithm

The data from the python serial monitor is retrieved and send to the com port where the IC is connected to the computer. It is sent in the form of an array itself. This helps the user to assign each index for specific purpose. So as soon as the code starts running the data from the controller is directly sent to the microcontroller without any delay.

2.4 Robot's Stability Calculation

2.4.1 Case 1: Inclination

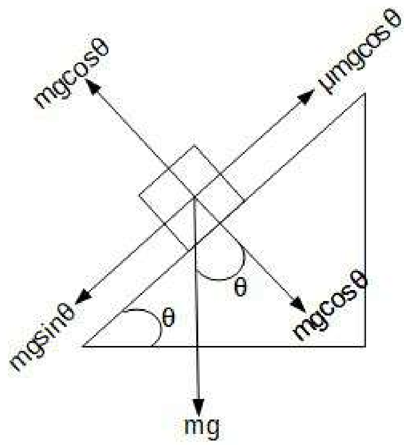


Figure 2.31: Robot on an inclination

Now robot can either climb an inclination or be moving forward on an inclined plane. In either case there is a chance for it to topple.

So, for the stability of robot we must calculate the critical angle for inclination, i.e., the angle of inclination at which the robot may topple.

The basis of our calculation is **Newton's law of motion**. We are considering the free body diagram of robot with a mass 'm', and a gravitation acceleration acting on it as 'g'.

From the figure we can see the force mg acting towards ground and its cosine component acting towards inclination. Now from the figure

$$mgsin\theta = mgcos\theta \tag{2.1}$$

$$tan\theta = \mu \tag{2.2}$$

$$\theta = tan^{-1}(\mu) \tag{2.3}$$

The other case of our robot in which it may topple is when the robot's front and back tracks are not collinear. This can be deduced by calculating the height of centre of gravity of the bot. This can be calculated from the critical angle. We are taking the assumption of the static stability factor. **In** eq^n**(3.3) we calculated critical angle**.

$$tan\theta = \frac{w}{2 * h_{cog}} \tag{2.4}$$

$$h_{cog} = \frac{w}{2 * tan\theta} \tag{2.5}$$

2.4.2 Case 2: The change in centre of mass and centre of gravity when front and back track suspension are contracting, relaxing with alternate heights of the four tracks

Now this theory is assumed by creating an analogy. We consider the body of the robot, i.e., the robot's chassis to be a square for simplification. Now this square is divided into four more equal squares.

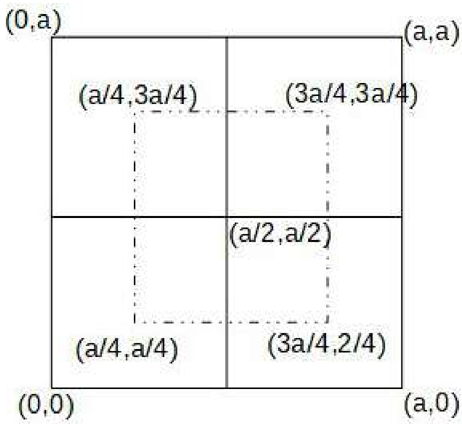


Figure 2.32: Analogy of chassis body with a square in Cartesian system

From the figure we can understand how the assumptions are made. The very first analogy is that of chassis being a square, the second is considering this square to be placed on the Cartesian coordinate system.

Now we are assuming that whenever one track of chassis is changing its alignment with respect to other tracks then the *cog* and *com* of the body will move towards the opposite direction. This theory is based on the fact that centre of gravity of square is at the same place as centre of mass, i.e., in the centre of the square. Thus, if the track changes direction this will be assumed as a square going missing from the set. Let us see one case.

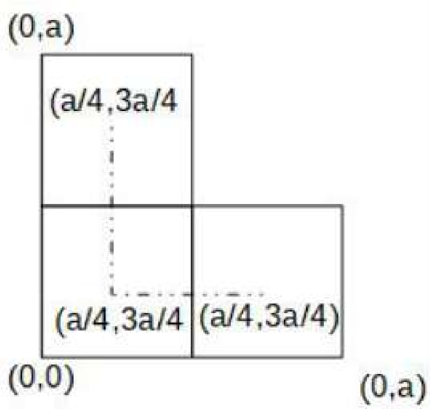


Figure 2.33: Analogy of one leg in different position

Here we are assuming that when one track is not aligned with other ones than we my remove one square to calculate the shift of centre of mass or centre of gravity.

The calculation is as follows,

$$X = \frac{m * ((a/4) + (a/4) + (3a/4))}{3m} \tag{2.6}$$

$$X = \frac{5a}{12} \tag{2.7}$$

$$Y = \frac{m * ((a/4) + (a/4) + (3a/4))}{3m} \tag{2.8}$$

$$Y = \frac{5a}{12} \tag{2.9}$$

In the above equations, m is mass of each square body, a is side length.

From eq (3.7) and (3.8), we see the shift in the Centre of Gravity (COG) and COM of the system. This analogy helps us to understand the shift of balance and mass in the robot as well. If we consider the robot as the same system, then these assumptions help us to understand the shift in angle when the tracks are moving independently.

This was one such case where the system is changing, there will be other cases as well but this basis of calculations will easily help us to deduce a system for them as well.

2.5 On-board Jammer

Relevance: In our project, we are using jammers especially to counter RCIED (Remotely Controlled Improvised Explosive Device), which are normally operated on GSM or CDMA (dual band technology), mostly ranging from 450MHz to 1900MHz bands.[8]

Proposed Technique: Cell Splitting, similar to mobile switching schemes, we have proposed this technique for our onboard jammer. Instead of using a single high power jammer, we subdivide it into lower power jammers for 450MHz and 900MHz respectively.[3]

Formula Used: Frequency

$$F = \frac{1}{2\pi\sqrt{L * C}} \tag{2.10}$$

where L, C are inductance and capacitance respectively, which can be varied according to target frequency.

CHAPTER 3

EXPERIMENTAL SETUP

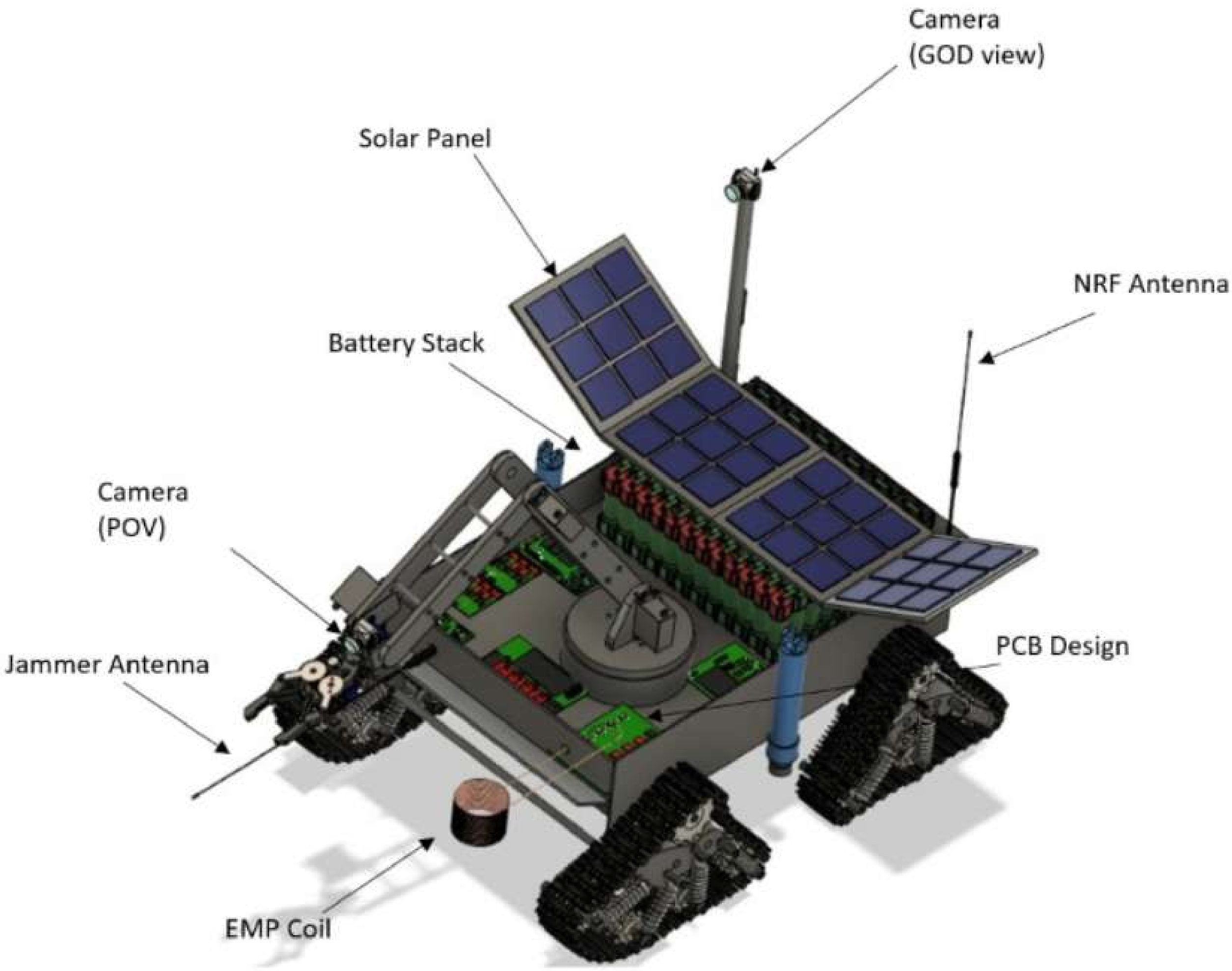


Figure 3.1: Final Assembly of Robot

3.1 Final Prototype of Enhanced EOD Robot

The final design of our Enhanced EOD Robot comprises:

- **Chassis with Quad Caterpillar Tracks with independent drive mechanism**: For all terrain mobility and tactical environment reliability, that is, if one of the tracks is damaged the other would still keep the bot mobile unlike conventional caterpillar tracks.

- **Detachable Manipulator arm with 6 degrees of freedom and Bladed Pincer with POV camera for defusal and disposal of IED**: Unlike Conventional Arm design with 2 DOF, it is analogous to human arm thus has a better reach. Being Detachable also makes it a better payload and accessory bot with varied capabilities.

- **On-board Jammer, EMP modules and other sensors**: 450-900MHz frequency specific Jammer and EMP module for RCIED and replacement of NLJD. These are on-board thus eradicate human and animal intervention in counter-IED operations

- **On-board Main and Auxiliary Power Unit**: This type of powering unit is best suited for tactical environment where the bot is ready to be deployed without fuss and insufficient battery power.
  1. Main Power Unit: 2 Layered Battery Stacks of 9 18650 2000mAh cells 3.7V each.In 4s fashion with 4s BMS to get 12.6V, a total of **25.2V**. 4s BMS is with 25A rating.
  2. Auxiliary Power Unit: Self Concealing Solar panels 6V 180mA, Size: 99mm x 69mm, 2 in series to get 12V and each 2 are connected in parallel to get 1.8A

- **Hydraulic Piston Mechanism**: When the bot encounter a difficult terrain, this mechanism would help it clear obstacles or prevent it from being a sitting duck in enemy territory by giving greater ground clearance.

- **RF Feed**: A God view RF Feed camera with FLIR and Night Vision.

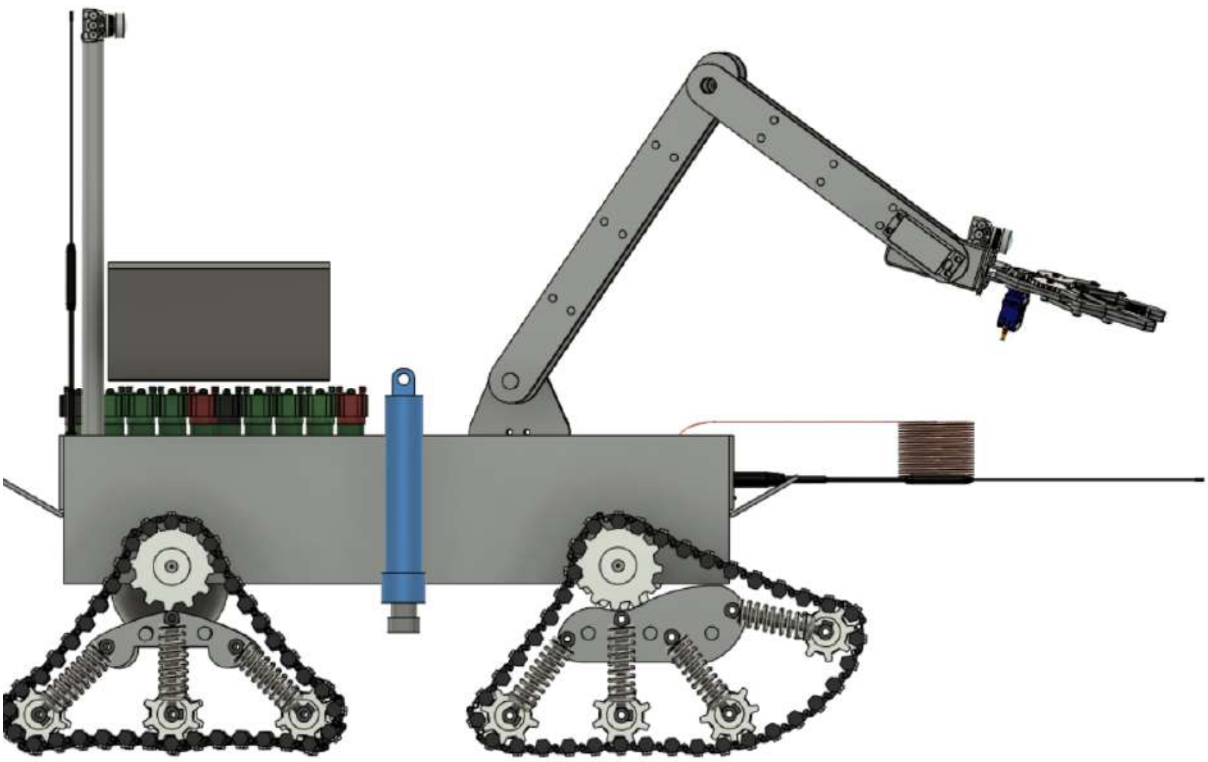


Figure 3.2: Side-view of Prototype

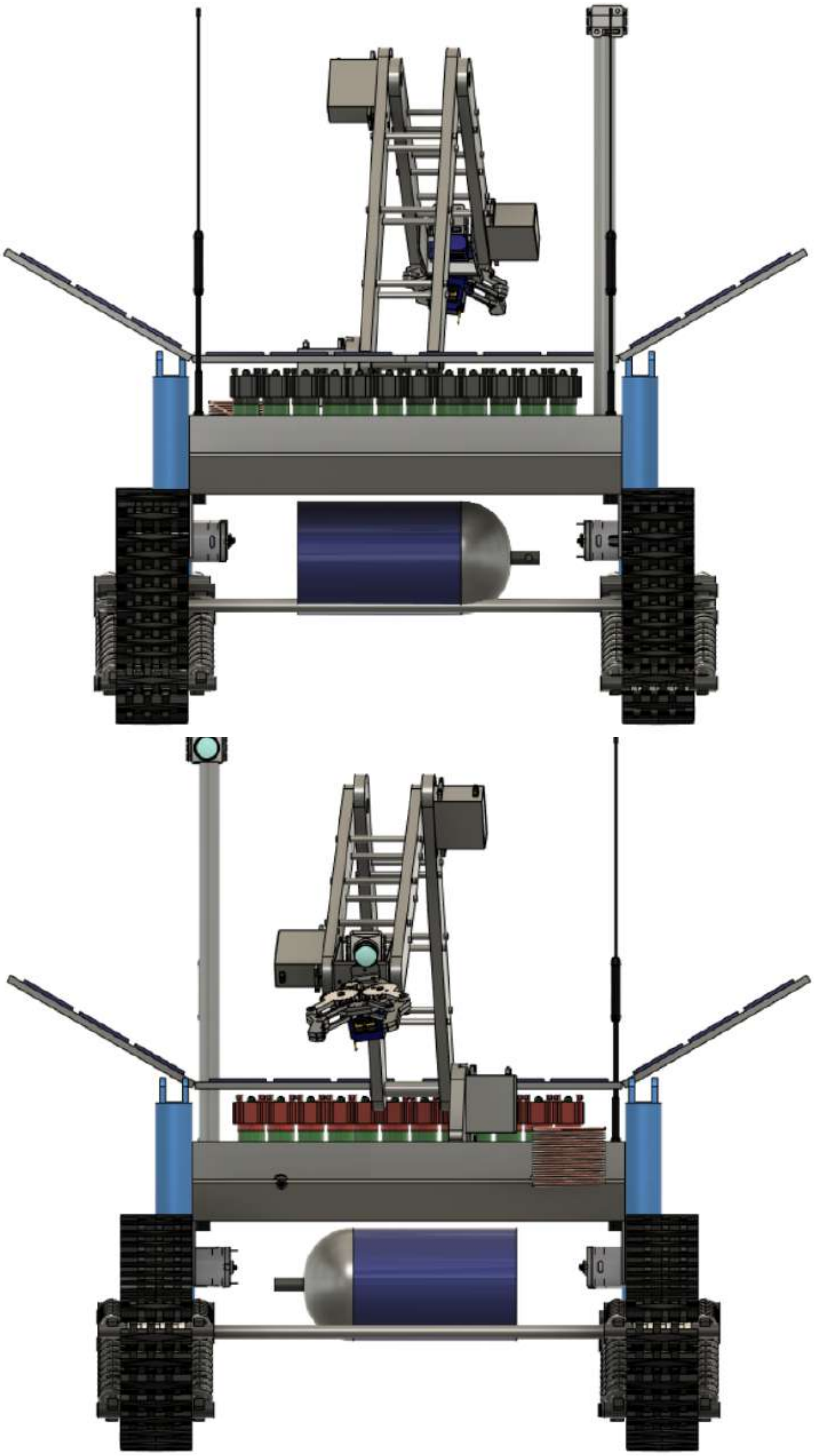


Figure 3.3: Back and Front View of Prototype with Hydraulic Fluid Cylinder

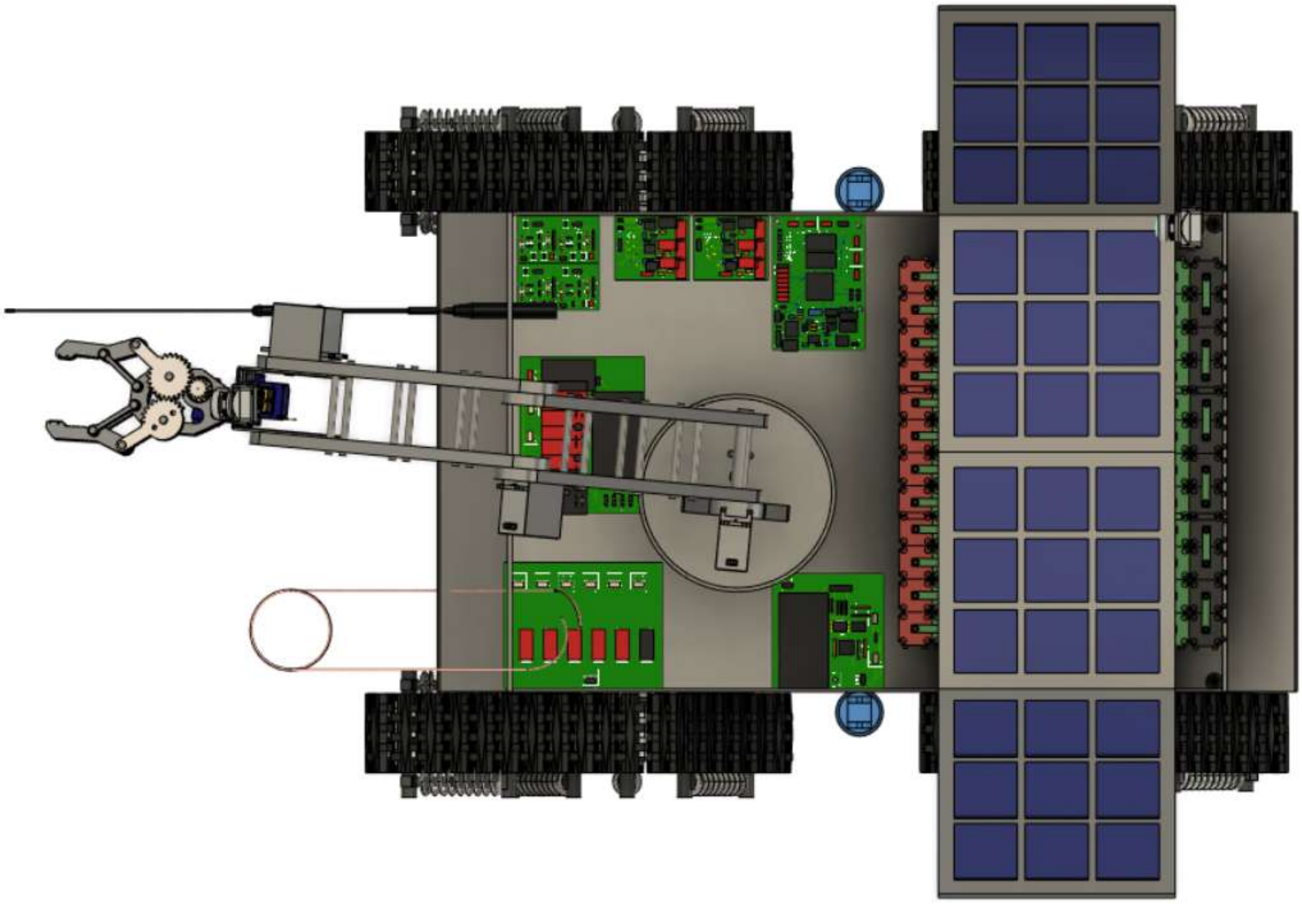


Figure 3.4: Top-view of Prototype with Electronic Circuits

3.2 URDF Robot Description

URDF is a robot description format written in XML language used to describe all the elements of the robot.

It consists of tags which are simulation specific and help to simulate the robot in Gazebo.

URDF of a robotic arm consists of three basic elements:

- Links
- Joints and
- Transmissions

- **Link**:Origin, mass, inertia, geometry and collision parameter of each link is defined.

```xml

<link name="base_link">
  <inertial>
    <origin
      xyz="-5.55111512312578E-16 0.0249999999999999 -0.00104090535604671"
      rpy="0 0 0" />
    <mass
      value="0.583626548245724" />
    <inertia
      ixx="0.00995277420976023"
      ixy="1.81979734761666E-17"
      ixz="6.94057493385789E-19"
      iyy="0.00725813933364075"
      iyz="-2.25406224192983E-18"
      izz="0.0169154818135838" />
  </inertial>
  <visual>
    <origin
      xyz="0 0 0"
      rpy="0 0 0" />
    <geometry>
      <mesh
        filename="package://arm_updated9/meshes/base_link.STL" />
    </geometry>
    <material
      name="">
      <color
        rgba="0.792156862745098 0.819607843137255 0.933333333333333 1" />
    </material>
  </visual>
  <collision>
    <origin
      xyz="0 0 0"
      rpy="0 0 0" />
    <geometry>
      <mesh
        filename="package://arm_updated9/meshes/base_link.STL" />
    </geometry>
  </collision>
</link>

```

Figure 3.5: Base Link URDF

- **Joint**:For each joint, parent link, child link, origin of joint ,joint axis and range of movement of joint is defined. Three basic joint types are: Fixed, Revolute, Prismatic

```xml
<joint
  name="joint_1"
  type="revolute">
  <origin
    xyz="0 0 0"
    rpy="0 0 0" />
  <parent
    link="base_link" />
  <child
    link="base" />
  <axis
    xyz="0 0 1" />
    <limit lower="-3.14" upper="3.14" effort="300" velocity="10" />
</joint>
```

Figure 3.6: Joint URDF

- **Transmission**:Type of transmission, controller used and actuator used is defined for all the joints.

```xml
<transmission name="trans_joint_1">
    <type>transmission_interface/SimpleTransmission</type>
    <joint name="joint_1">
      <hardwareInterface>hardware_interface/PositionJointInterface</hardwareInterface>
    </joint>
    <actuator name="joint_1_motor">
      <hardwareInterface>hardware_interface/PositionJointInterface</hardwareInterface>
      <mechanicalReduction>1</mechanicalReduction>
    </actuator>
 </transmission>
```

Figure 3.7: Transmission URDF

3.3 Moveit Motion Planning

Moveit is a ROS framework used for motion planning of a specific robot avoiding all the possible collisions. In this project moveit has been used as the tool for motion planning of the Robotic Arm. Moveit Setup Assistant is used to interact with the bot for motion planning.

3.3.1 Steps for motion planning setup

1. Loading URDF: The described URDF for our robot model is loaded

2. Optimize Self Collisions: Self collision matrix is generated, which describes the links of the robot for which collision need not be checked during motion planning. These links are generally the adjacent links which are always in collision

3. Defining virtual joints: Virtual joints are imaginary joints defined to fix the base of the robot to the simulated world frame

4. Planning Groups: Two different groups ,Arm and Gripper is made. Forward and Inverse kinematics needs to be solved for the arm group for which KDLKinematics plugin is used.No kinematics needs to be solved for the gripper as it is just opened and closed.

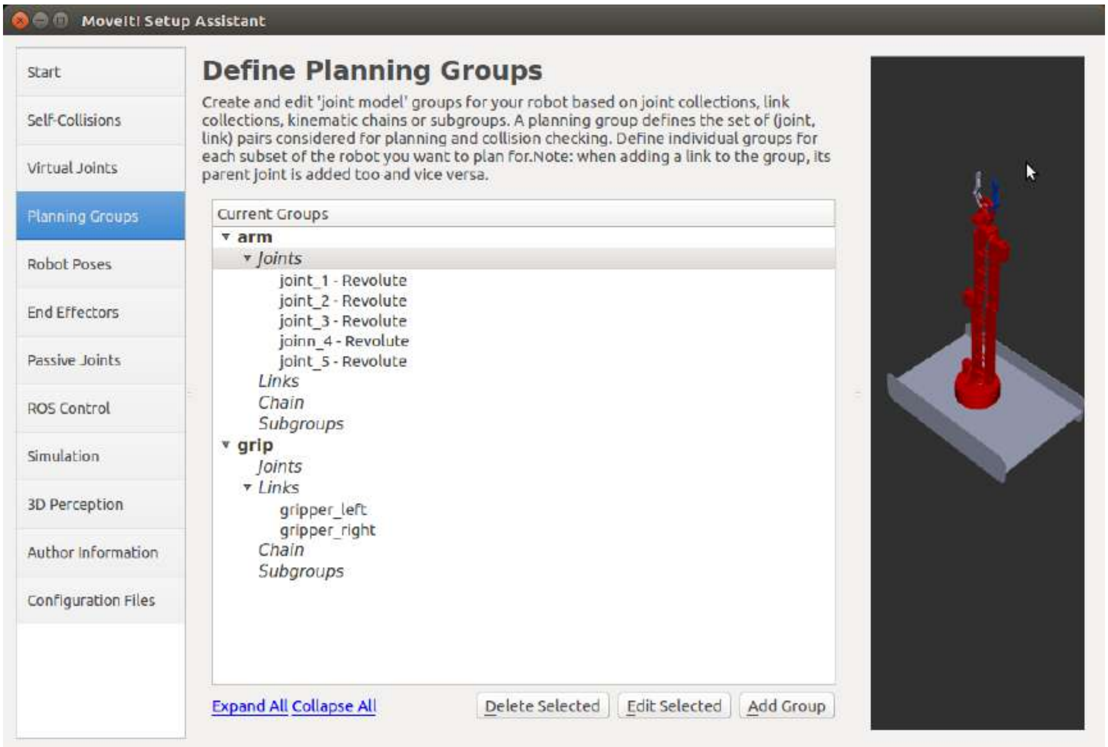


Figure 3.8: Planning Groups

5. Robot Poses: Here some default poses of arm group as well as the gripper group is defined.For arm group ,forward, backward, right, left and straight poses are defined and for gripper group open and close poses are defined. Then the moveit configuration package for the arm is generated

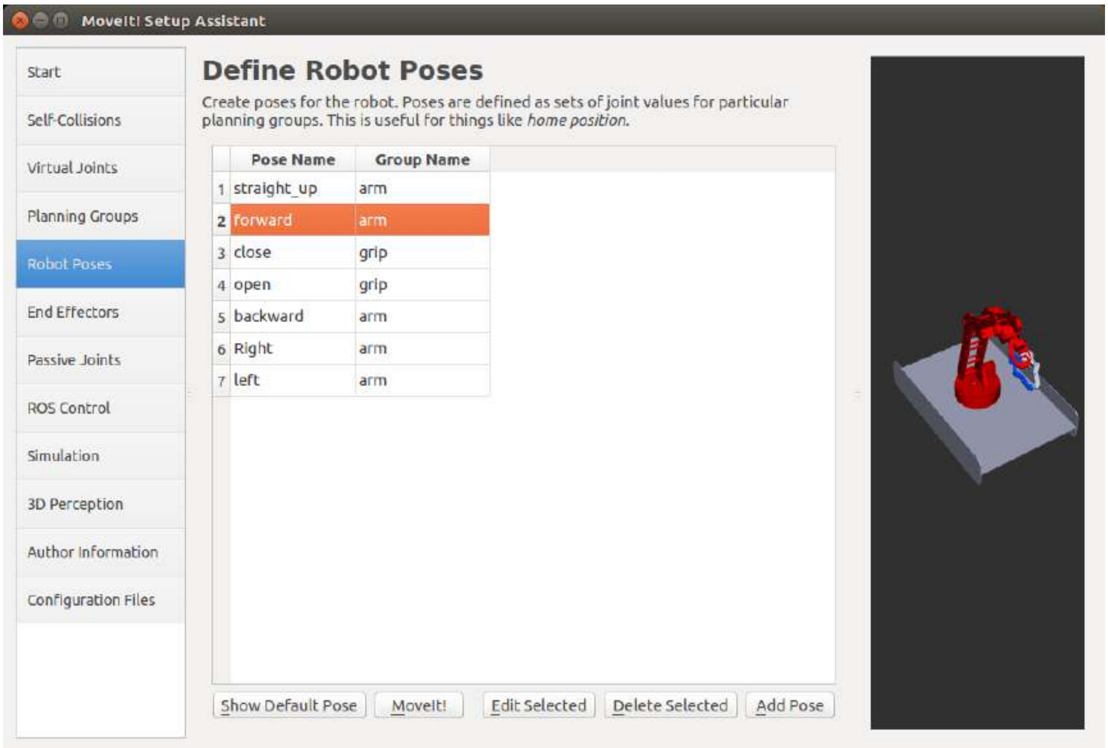


Figure 3.9: Robot Poses

6. Controllers: Joint trajectory controllers under position controllers is defined for each joint which helps to control the movement of each joint.

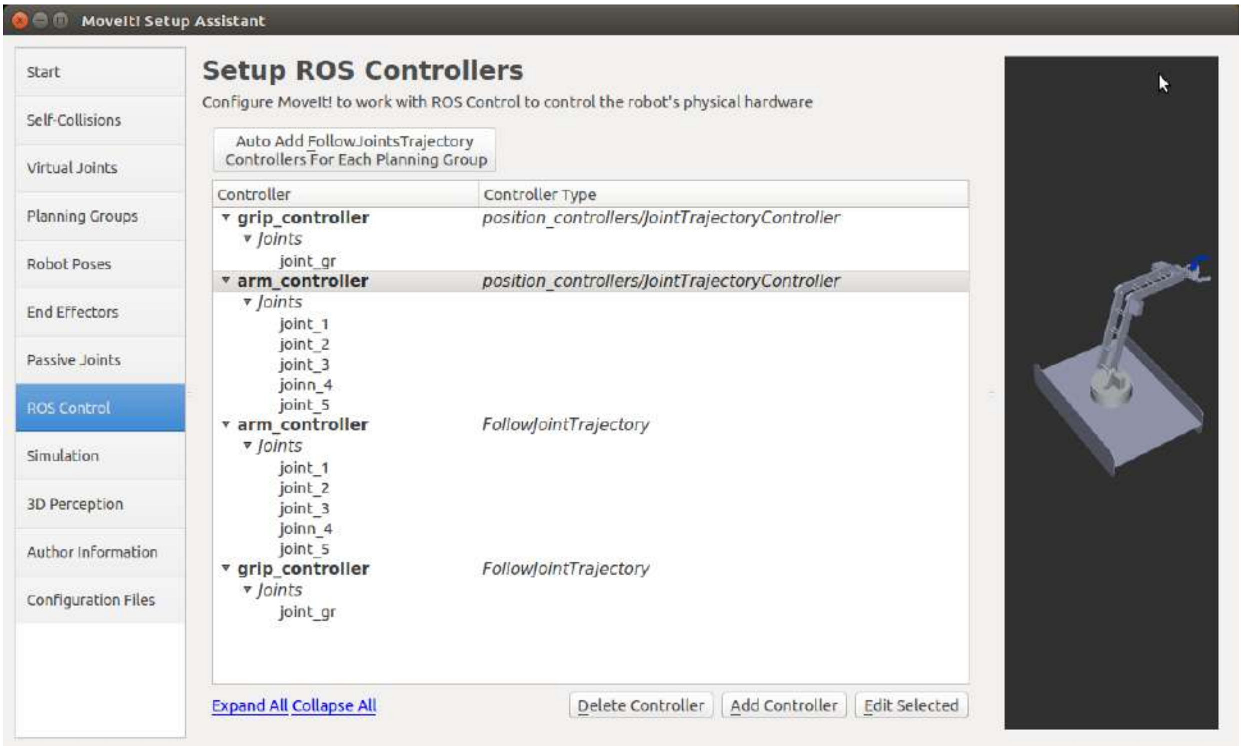


Figure 3.10: Controllers

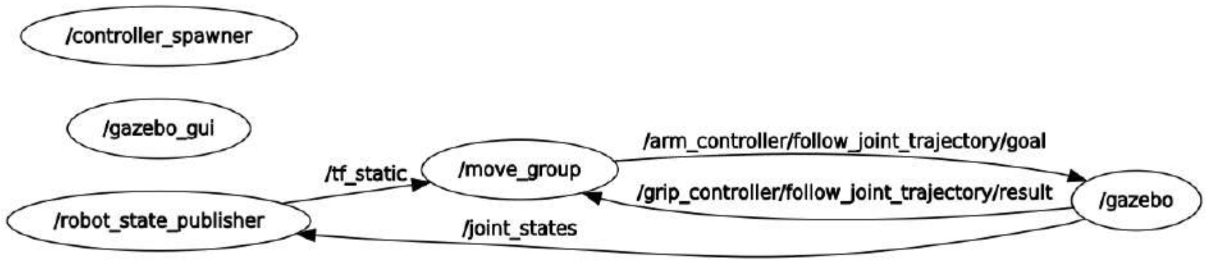


Figure 3.11: ROS nodes active during motion planning

- Starting the move group node: Move-group node is at the heart of Moveit motion planning, which integrates various components of the robot and provides the messages and services the robot needs. It collects the information of robot such as point cloud,transforms, joint state of the robot.Move-group collects the kinematics information from the URDF file of the robot which contains the information about its links and joints, and makes the bot ready for planning by activating all the controllers.

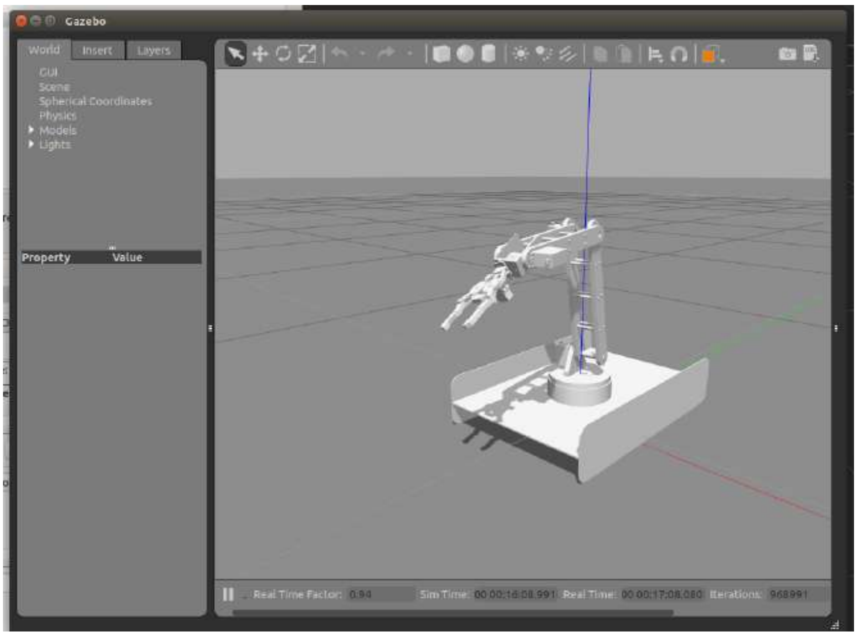


Figure 3.12: Robot model in Gazebo

- Launching the robot model in Gazebo: The robot model is launched in the Gazebo simulator, in which we can se the robot actuating the path planned by Moveit

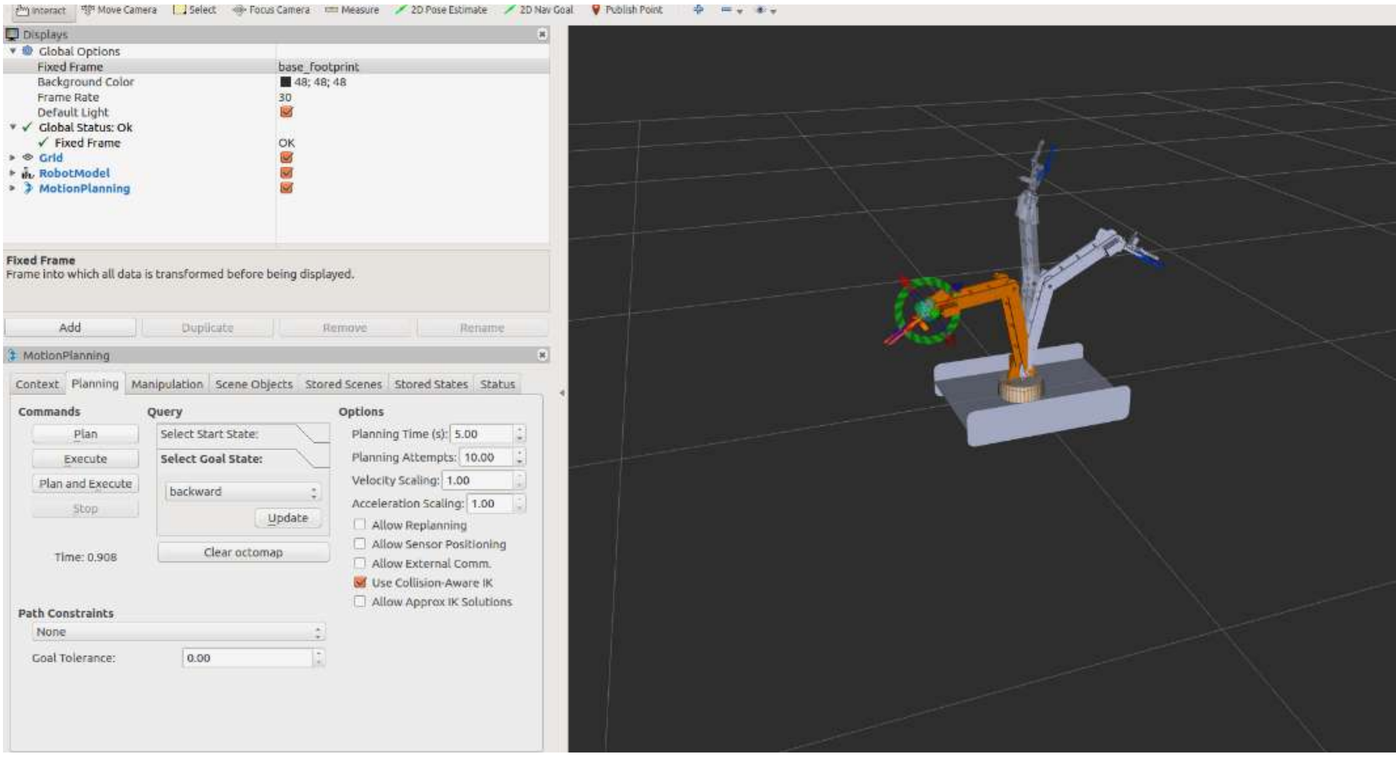


Figure 3.13: Planning in Rviz

- Starting RVIZ for Robot state visualization: Rviz is used to visualize the path being planned by the Moveit

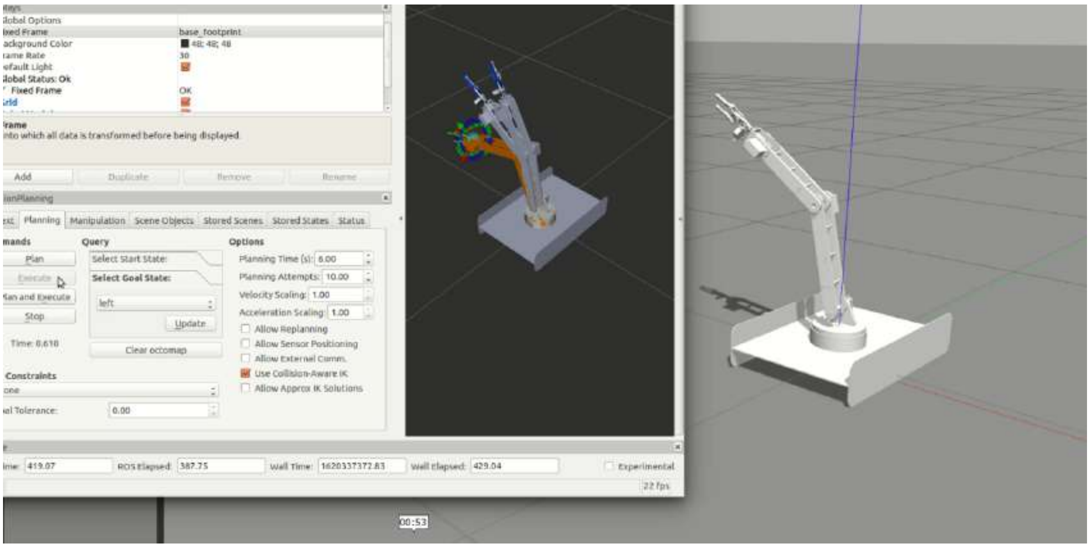


Figure 3.14: Simultaneous execution of plan in Gazebo

.

3.4 Circuit Designs

3.4.1 Micro-controller Design

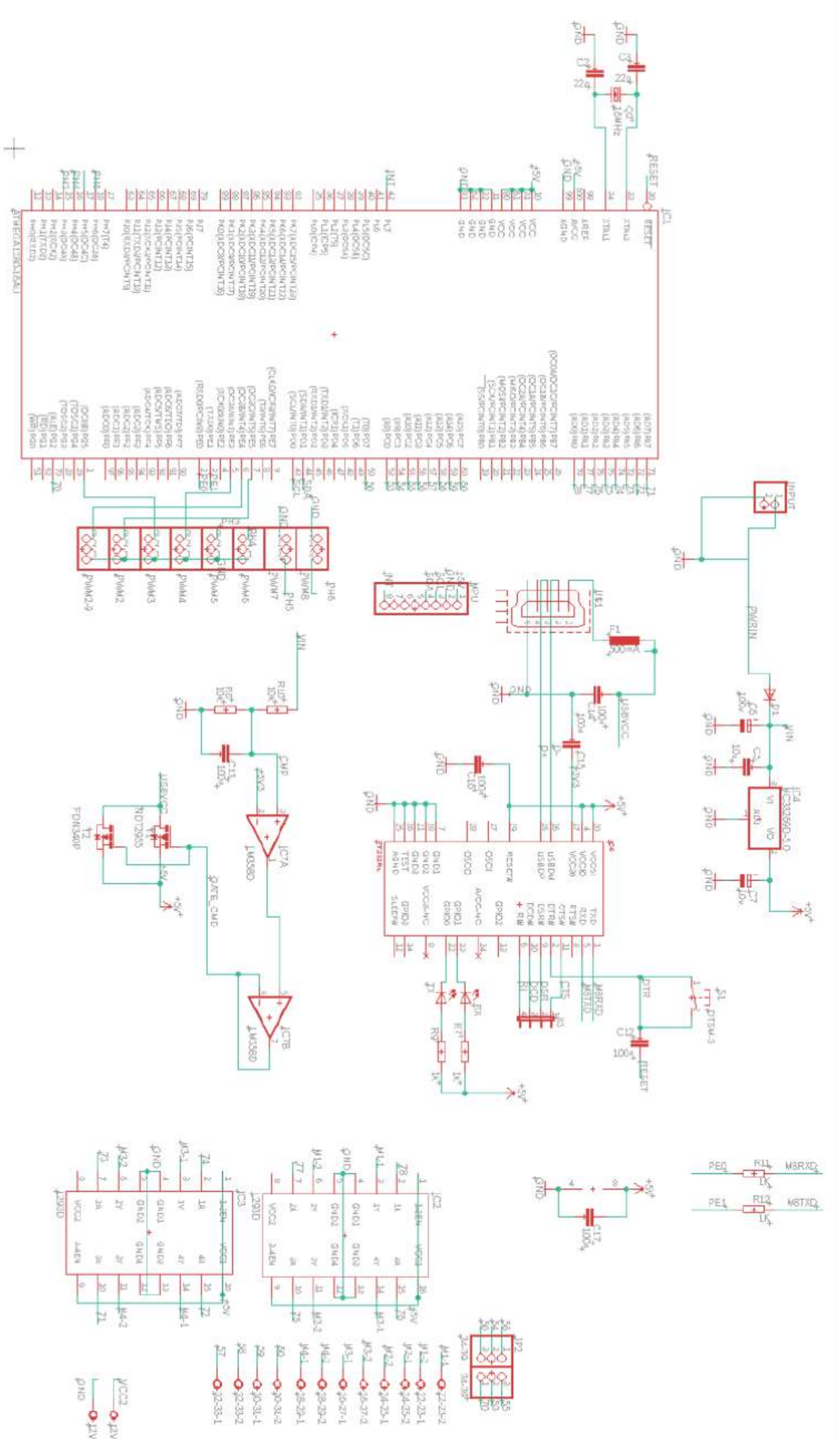


Figure 3.15: Microcontroller Schematic

A custom designed ATMEGA1280 based controller board. It can carry out all input output operations as it contains 8PWM pins for servo 12 digital pins to drive the DC motors. It contains a gycroscope (MPU6050) which communicates through the SPI and also includes H-bridge (L293d IC) which is integrated with the microcontroller.

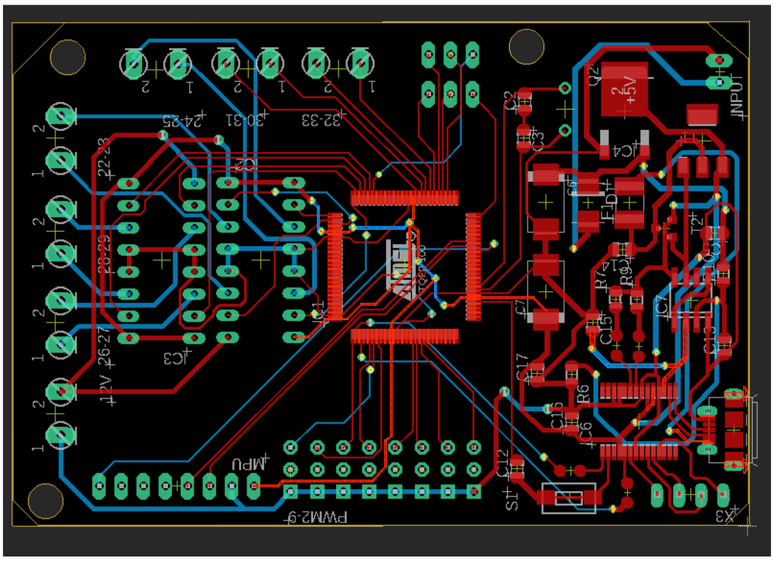


Figure 3.16: Microcontroller Gerber

Name	Value
Program Memory Type	Flash
Program Memory Size (KB)	128
CPU Speed (MIPS/DMIPS)	16
SRAM (B)	8192
Data EEPROM/HEF (bytes)	4096
Digital Communication Peripherals	4-UART, 5-SPI, 1-I2C
Capture/Compare/PWM Peripherals	4 Input Capture, 4 CCP, 16PWM
Timers	2X8 bit, 4x16 bit
Number of Comparators	1
Temperature Range (degree C)	-40 to 85
Operating Voltage Range (V)	1.8 to 5.5
Pin Out	100

Figure 3.17: Microcontroller Specifications

3.4.2 On-board Jammer

Jammer is an Electronic Countermeasure (ECM), which is used to block or interfere with wireless communications. A jammer transmits amplified signals added with noise over the same frequency which is meant to be blocked.

A jammer comprises 3 sub circuits: LC Oscillator, RF Amplifier and Noise Generator.

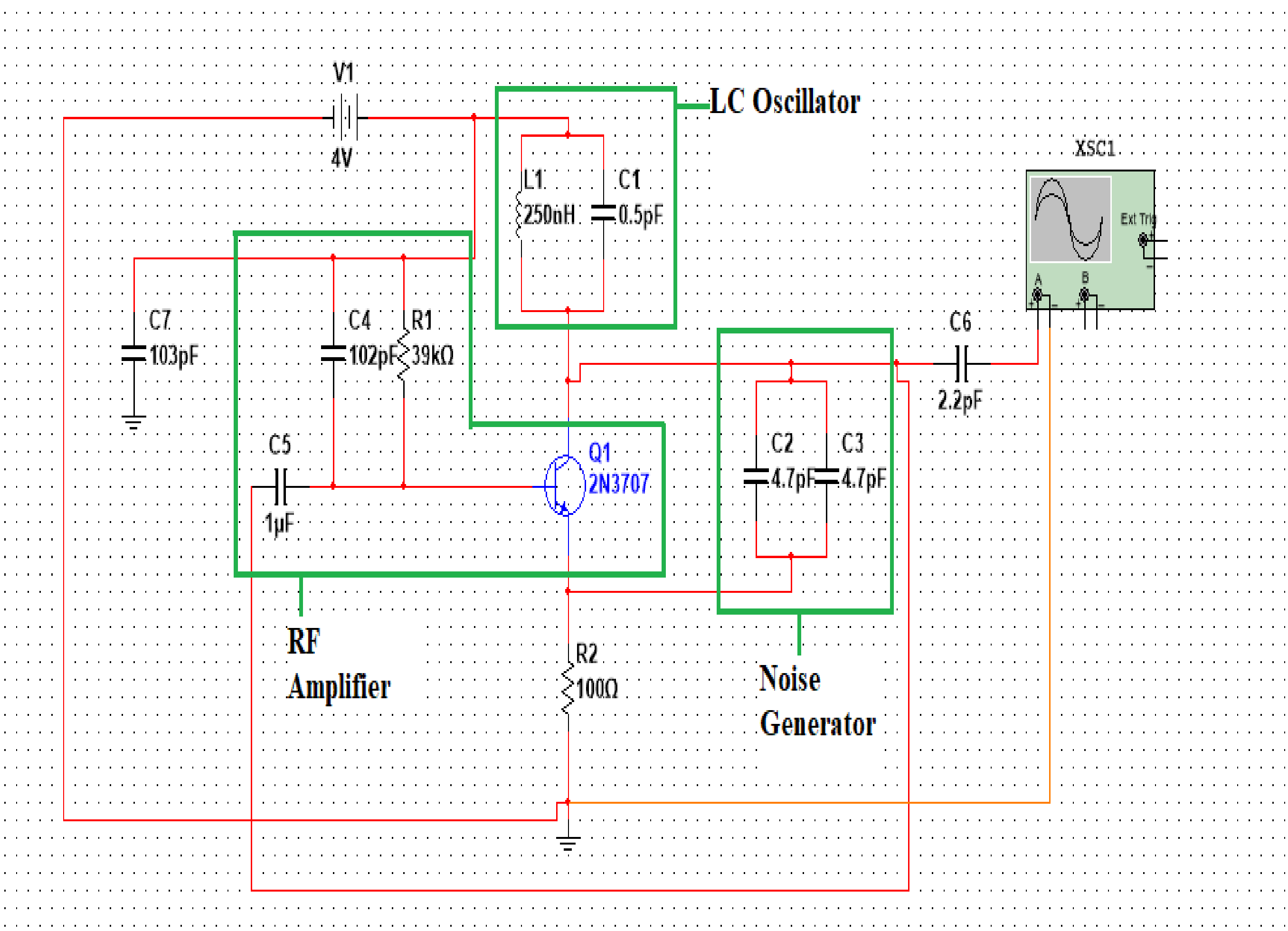


Figure 3.18: 450MHz Jammer Circuit Schematic (designed using NI Multisim)

The LC oscillator can be tuned to the target frequency by varying the values of inductor and capacitor. The RF amplifier amplifies the signal generated by the oscillator to which noise is added by boost feedback and this signal is filtered and transmitted via antenna.

Frequency Band	Inductance	Capacitance	Frequency Generated
450MHz	250nH	0.5pF	450.158MHz
900MHz	125nH	0.25pF	900.316MHz

Figure 3.19: Jammer Frequency Table

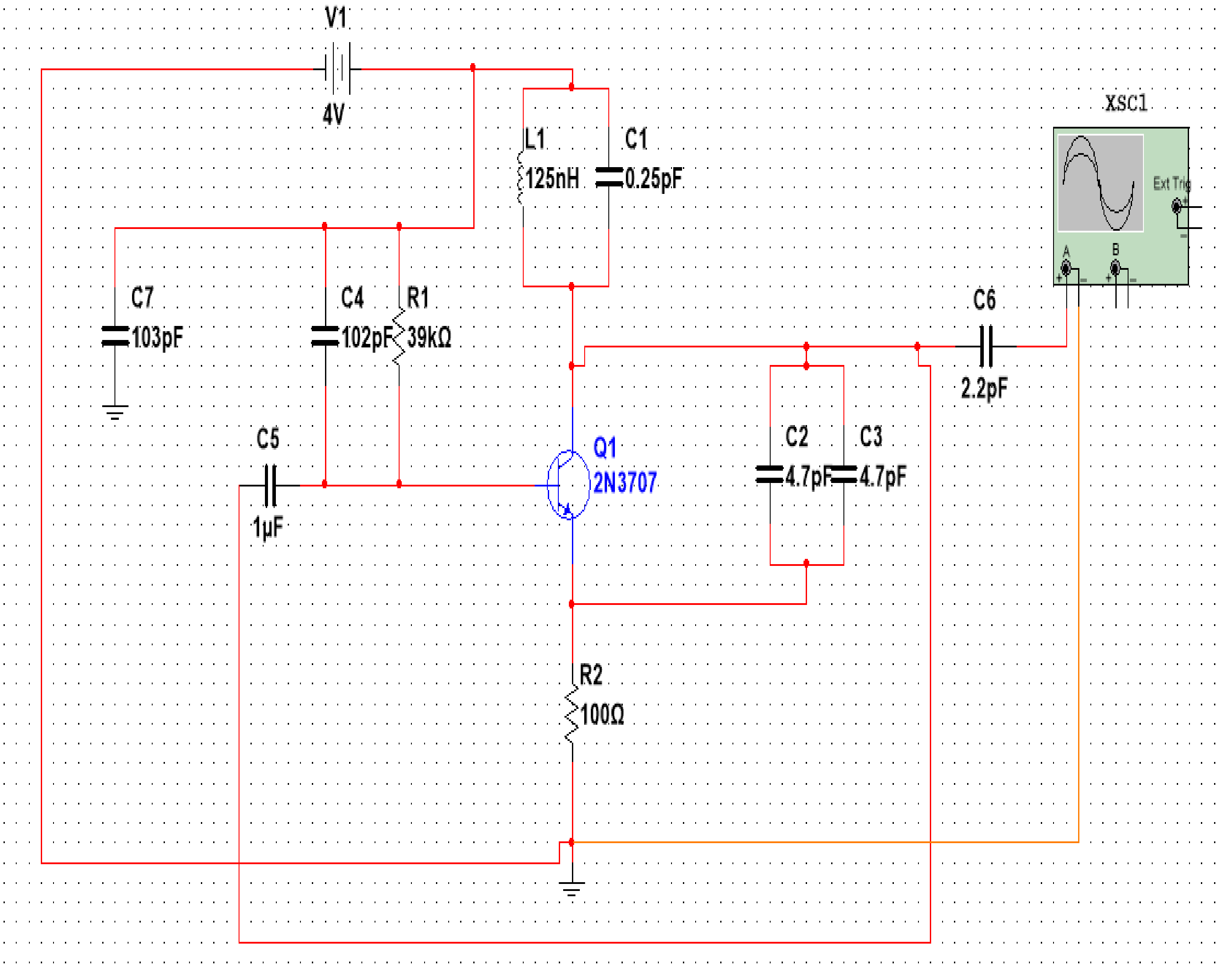


Figure 3.20: 900MHz jammer circuit schematic (designed using multisim)

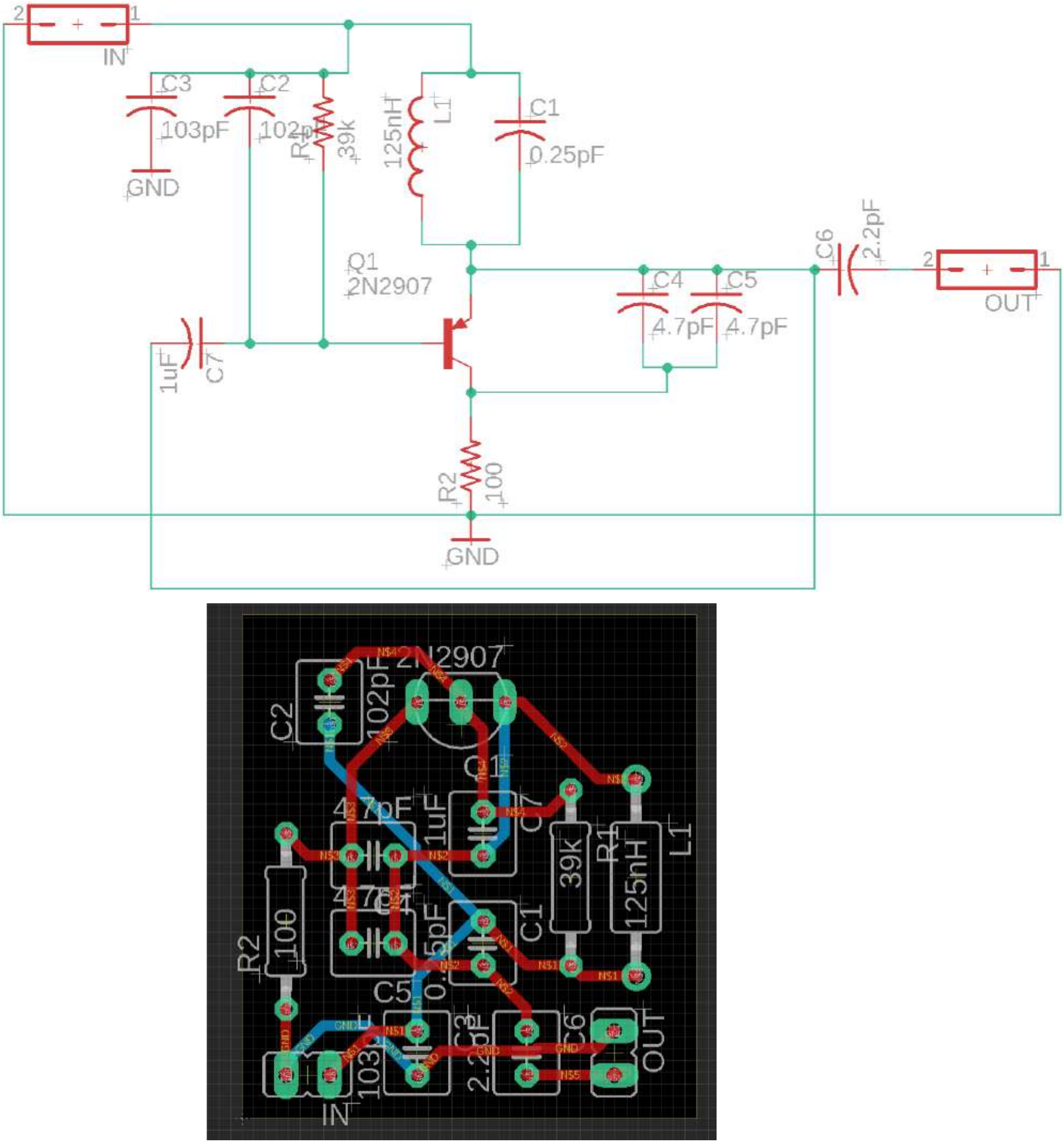


Figure 3.21: Jammer Schematic and Gerber File

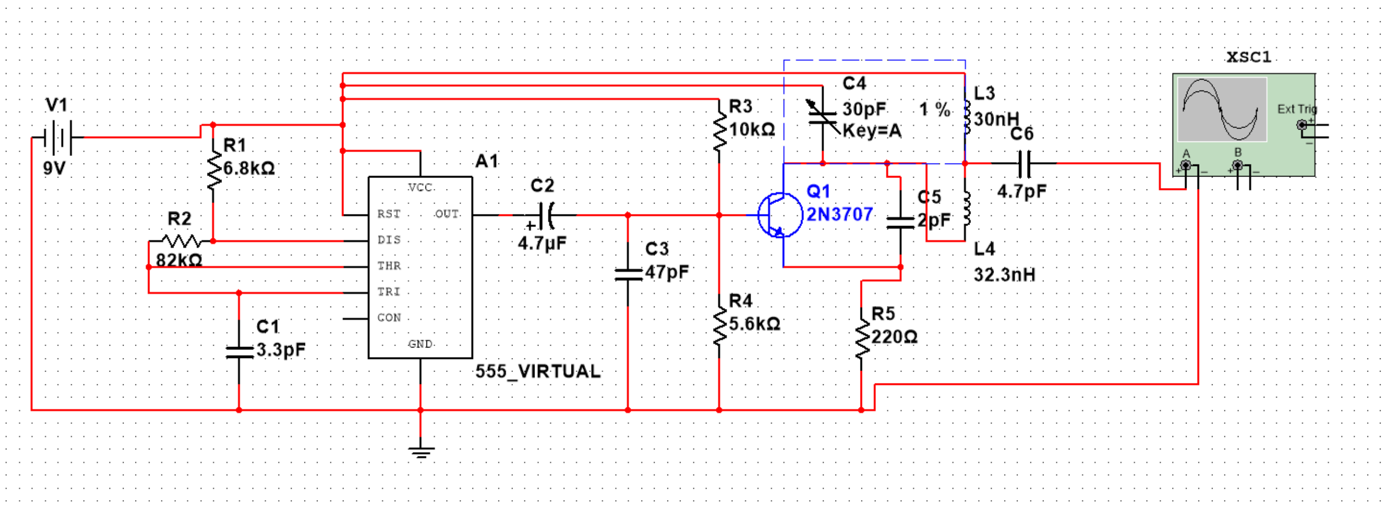


Figure 3.22: Jammer With variable capacitor

The above circuit has a variable capacitor with capacitance ranging from 3-30pF , which gives an output frequency in the range of 237-750MHz.

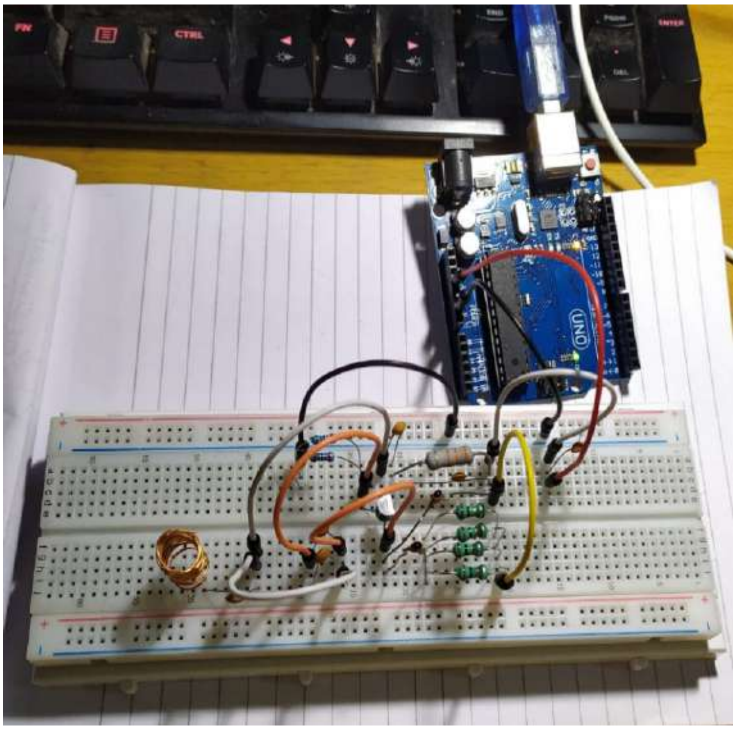


Figure 3.23: 900MHz Jammer Hardware Circuit

The above circuit is a 900MHz circuit designed specifically for GSM 900MHz band(INDIA UP WEST).

3.5 Control and Communication System

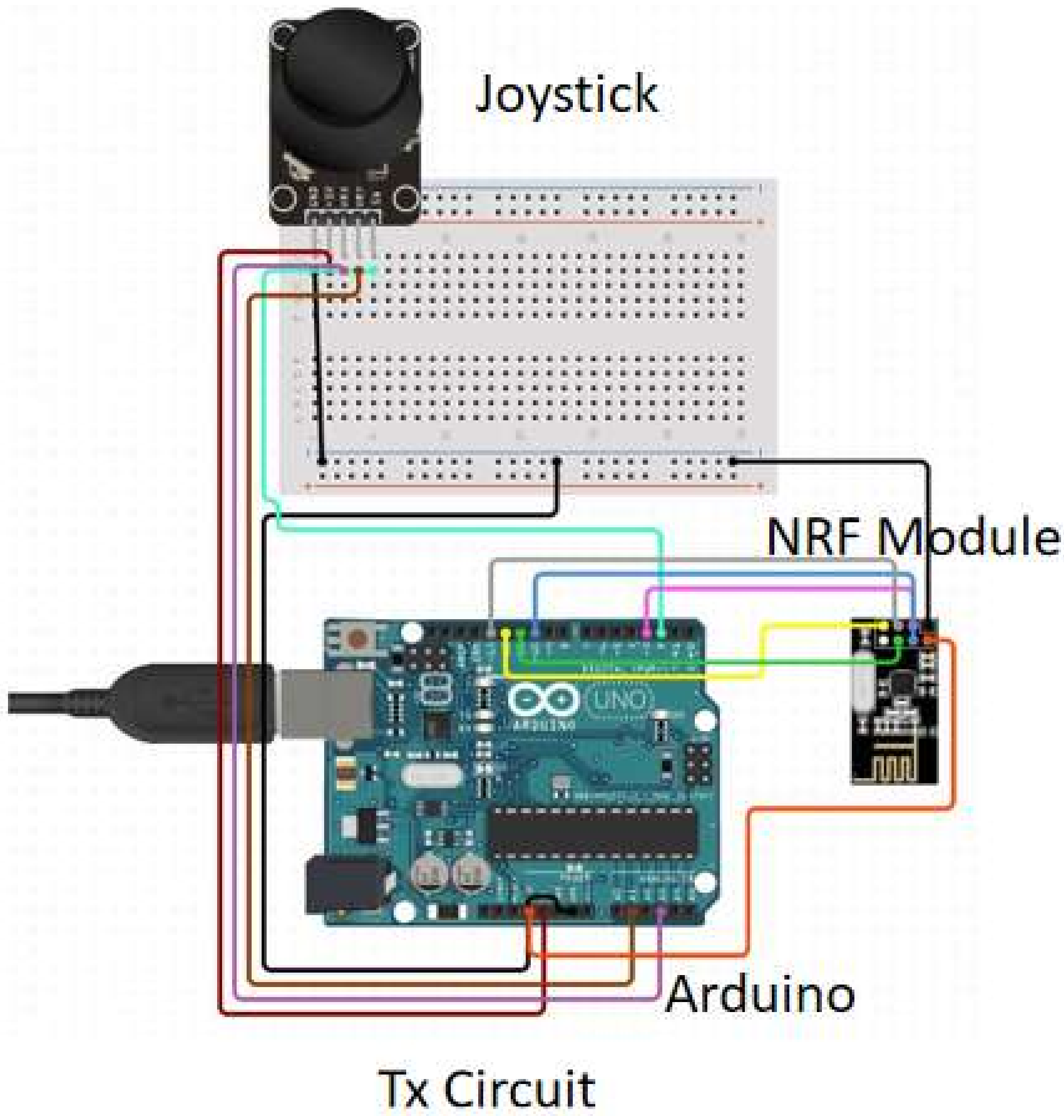


Figure 3.24: Transmission Circuit Schematic

The joystick/controller input would be transmitted to the bot from the base station via RF module using the frequency of 2.4GHz, thus communications will not be affected by our own jammer as it uses a separate band.

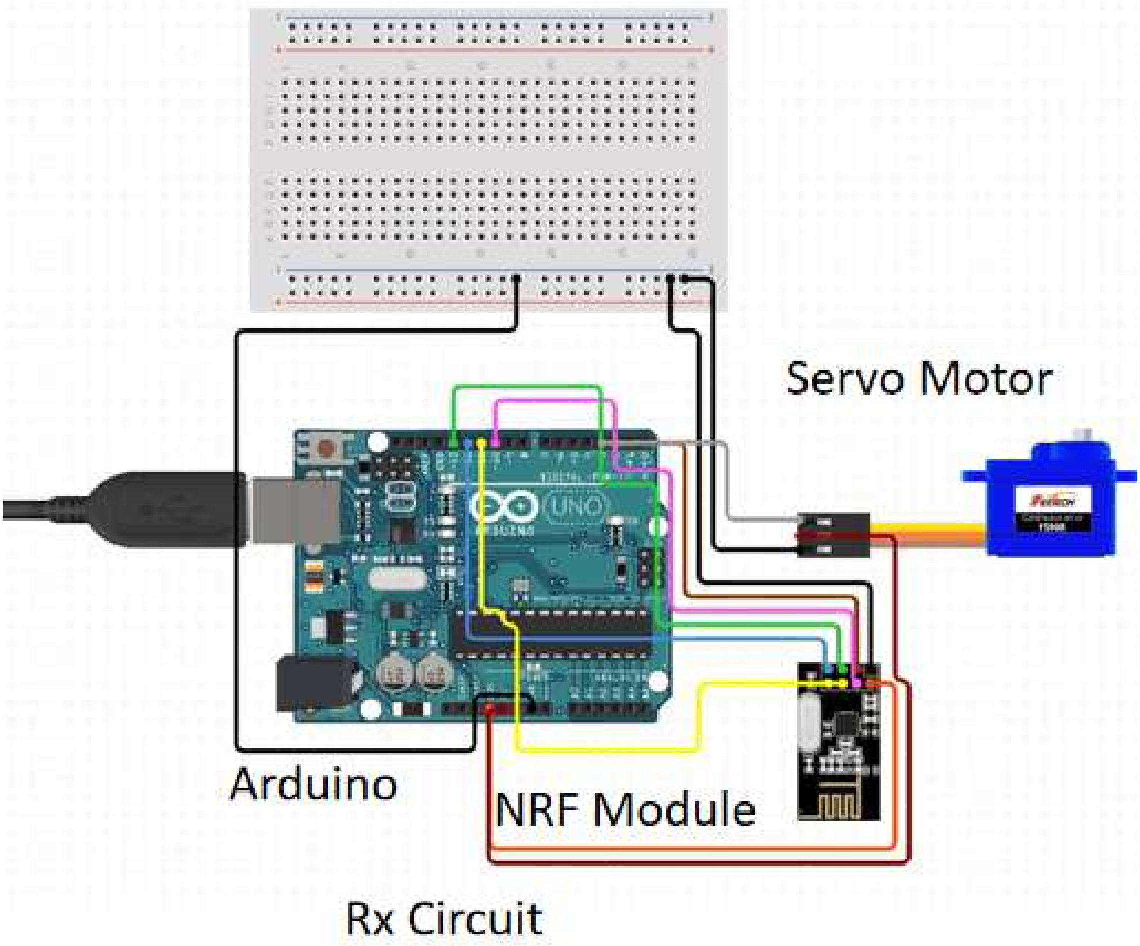


Figure 3.25: Reception Circuit Schematic

On reception of signal from base station, the particular component for which the signal was meant which come into action, for example movement of motors, pistons, circuit swtiching etc.

The Control System Setup was made using two Arduino Micro-controllers with transmitter and receiver RF modules, while the control system GUI was made using Serial Processing Software.In the GUI each button is mapped to a particular function on bot reception array resulting into variance in values when buttons are toggled,thereby indicating the control of robot.

Figure 3.26: Control System Setup

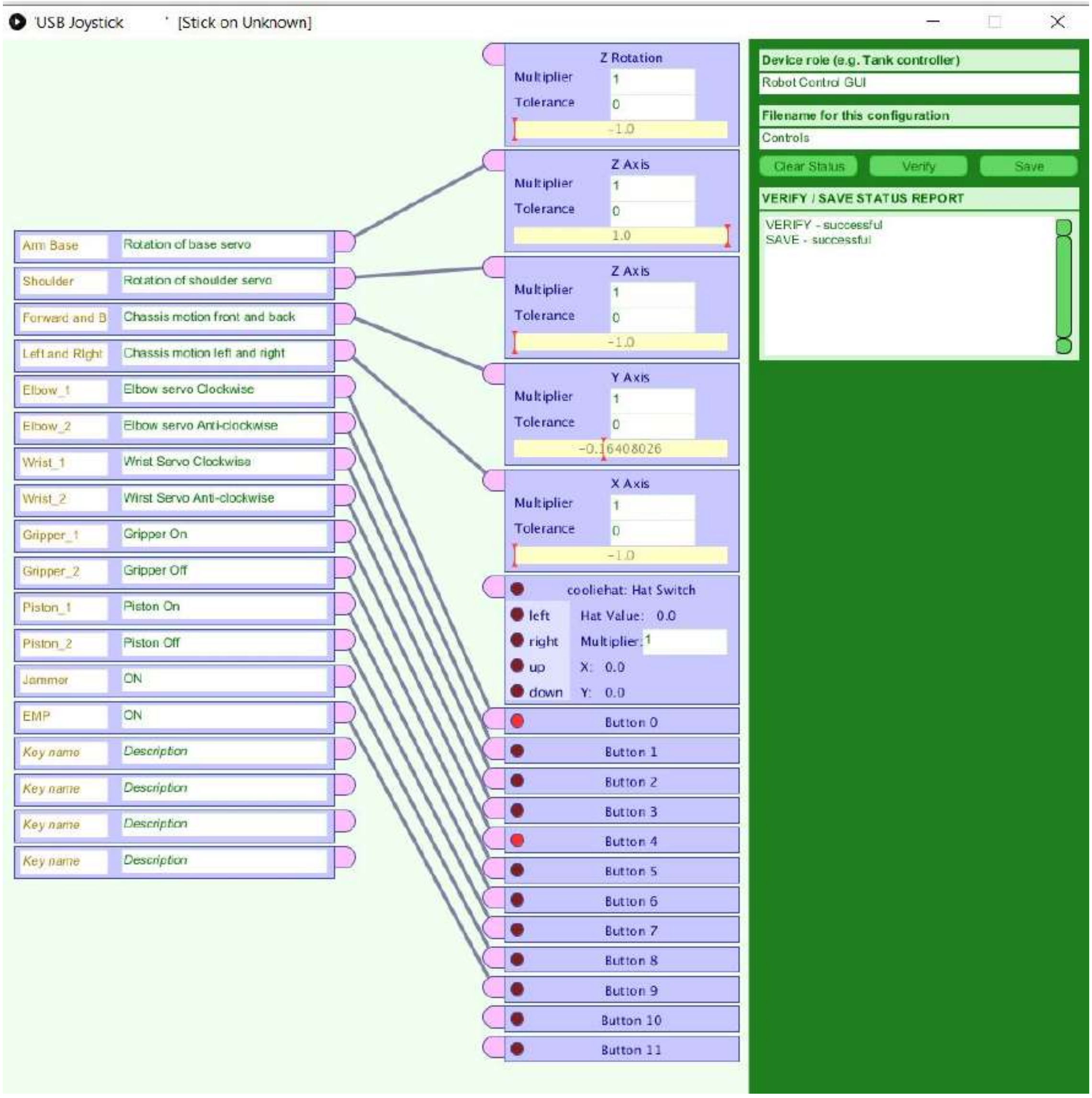


Figure 3.27: Control System GUI

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Belt Link and Suspension Stress Analysis

Static and Dynamic Stress Analysis was performed using Fusion 360 on a single belt link of caterpillar track and shock absorber of suspension, to determine the specific material to be used for industrial manufacturing and also the ultimate strength of that material.

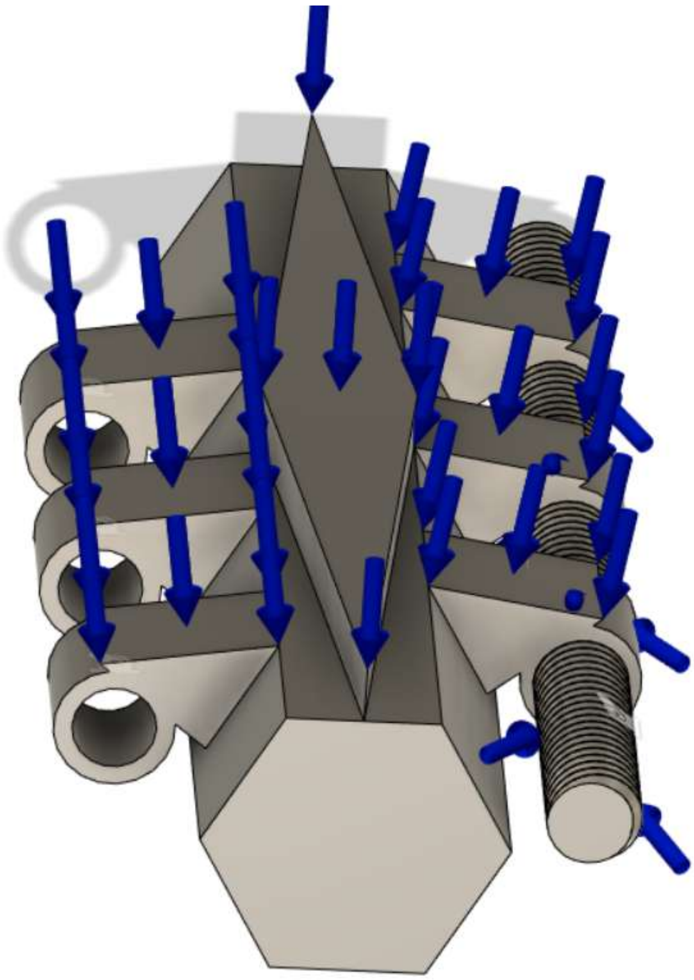


Figure 4.1: Static Stress Directions on Belt Link

4.1.1 Case 1: 0.5N Load Analysis on Iron Gray Material

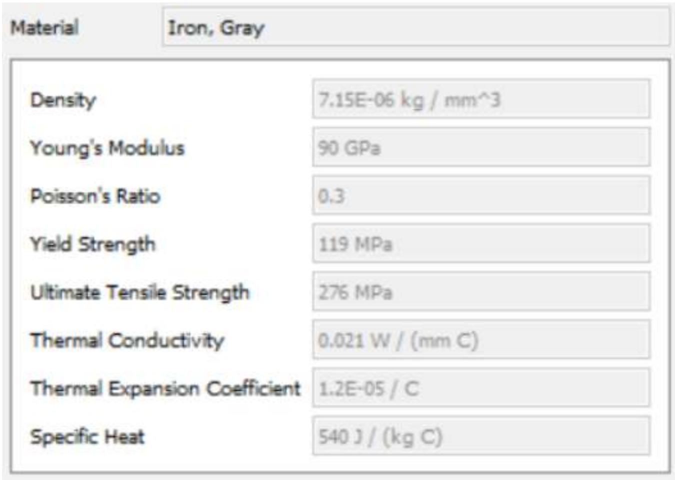


Figure 4.2: Iron Gray Material Properties

Result:Safety Factor 15

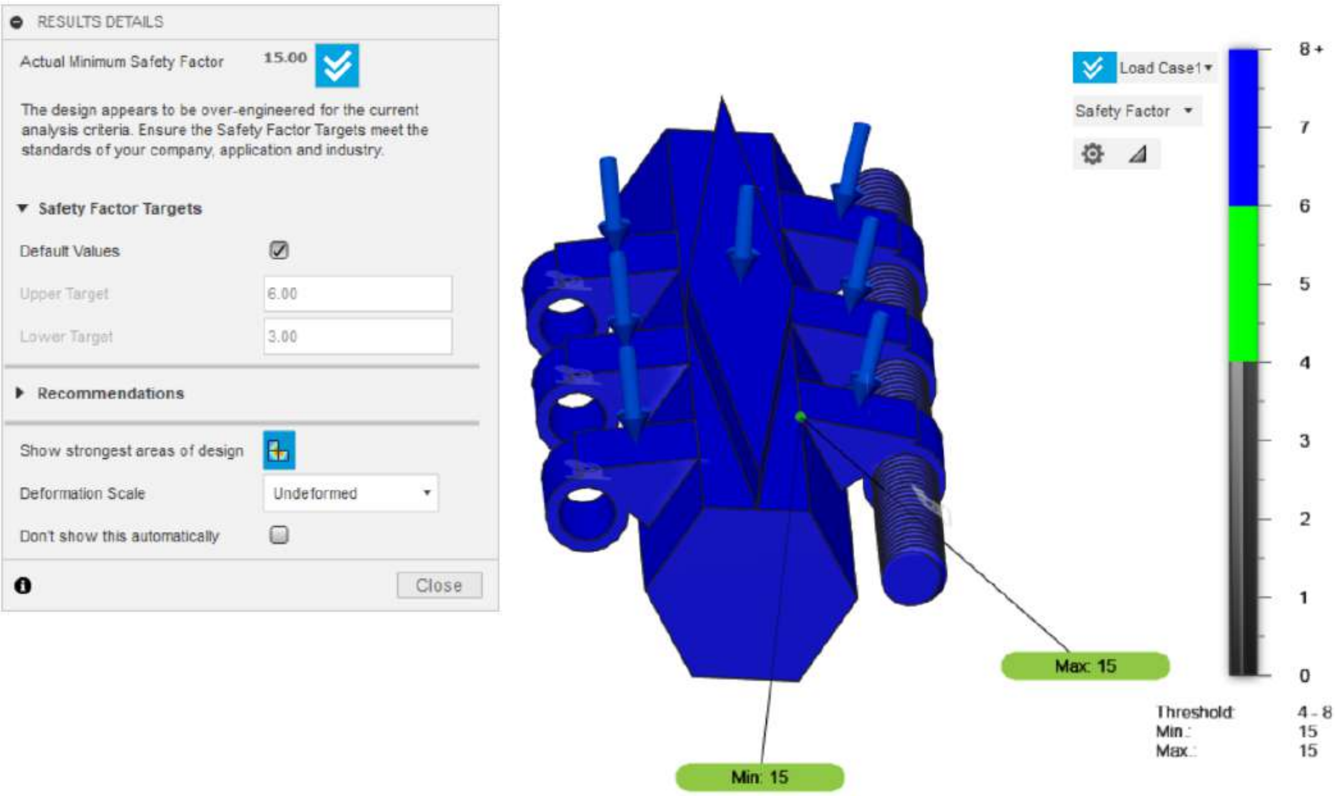


Figure 4.3: Belt Link Safety Factor for 0.5N Load

Inference: The belt link has maximum safety factor of 15 which far above the optimum range thus it can easily endure 0.5N load.

4.1.2 Case 2: 500N/50Kg Load Analysis on Iron Gray Material

The material under test was analysed for stress of 500N(50Kg).

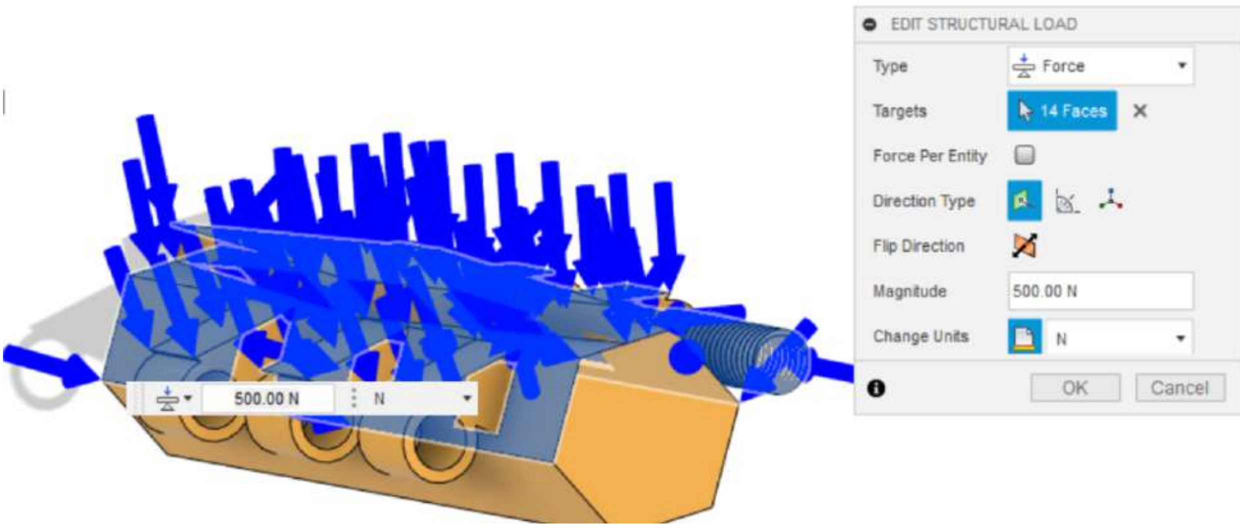


Figure 4.4: 500N structural load

Result: Safety factor 1.74

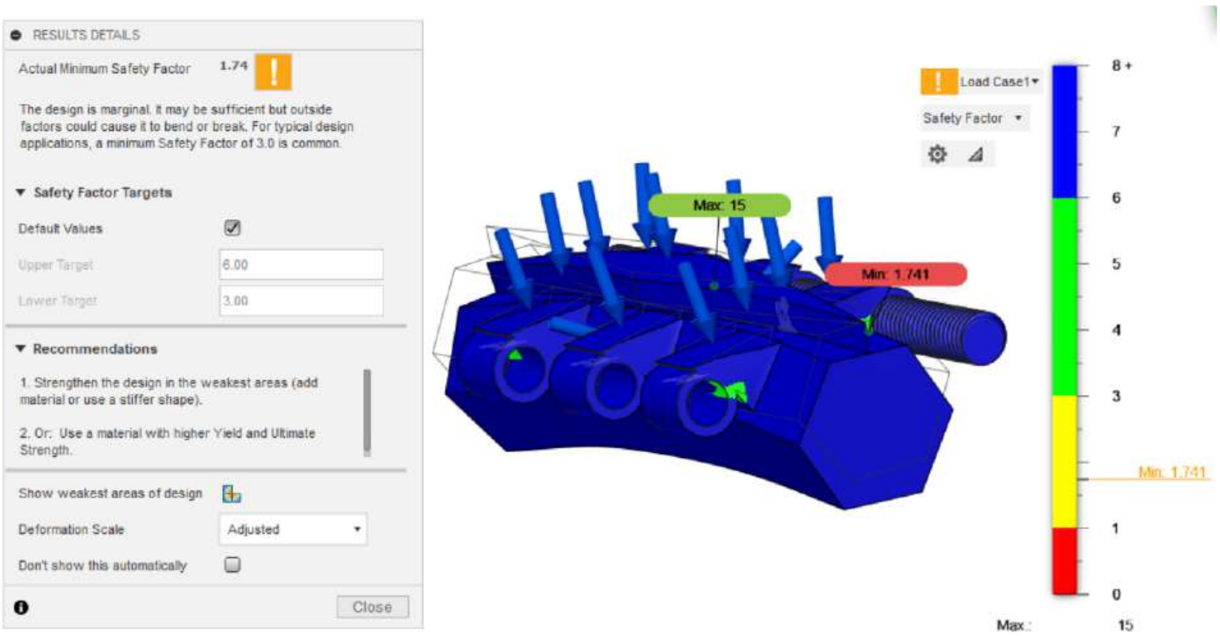


Figure 4.5: Belt Link Safety Factor for 500N Load

Inference: Noticeable deformation is observed with a poor safety factor of 1.74 when Iron Gray Material is loaded with stress of 500N, thus the belt link of this material can endure very low loads of under 50Kg.The solver recommends to use a material of higher ultimate and yield strength

4.1.3 Case 3: 500N/50Kg Load Analysis on High Strength Structural Steel

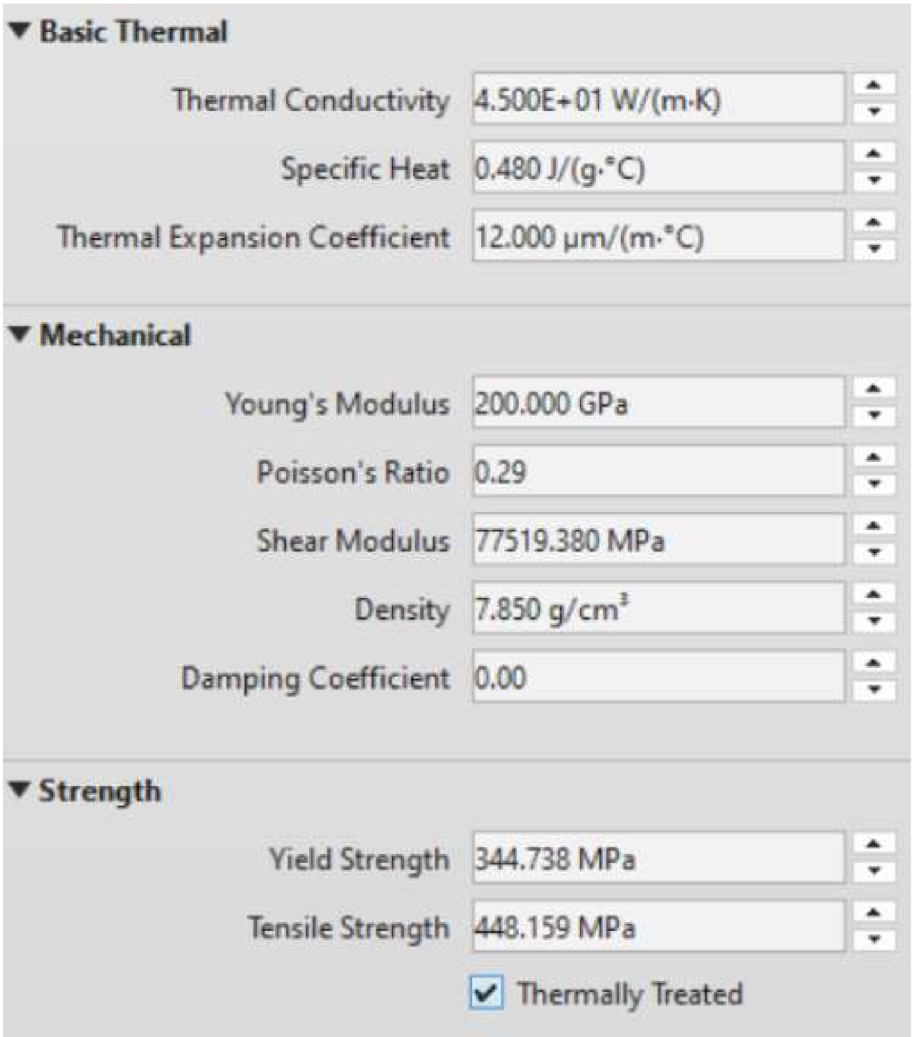


Figure 4.6: High Strength Structural Steel Material Properties

Result: Using High Strength Structural Steel with greater Yield and Ultimate Strength than Iron Gray, the solver data provided the analysis as follows:

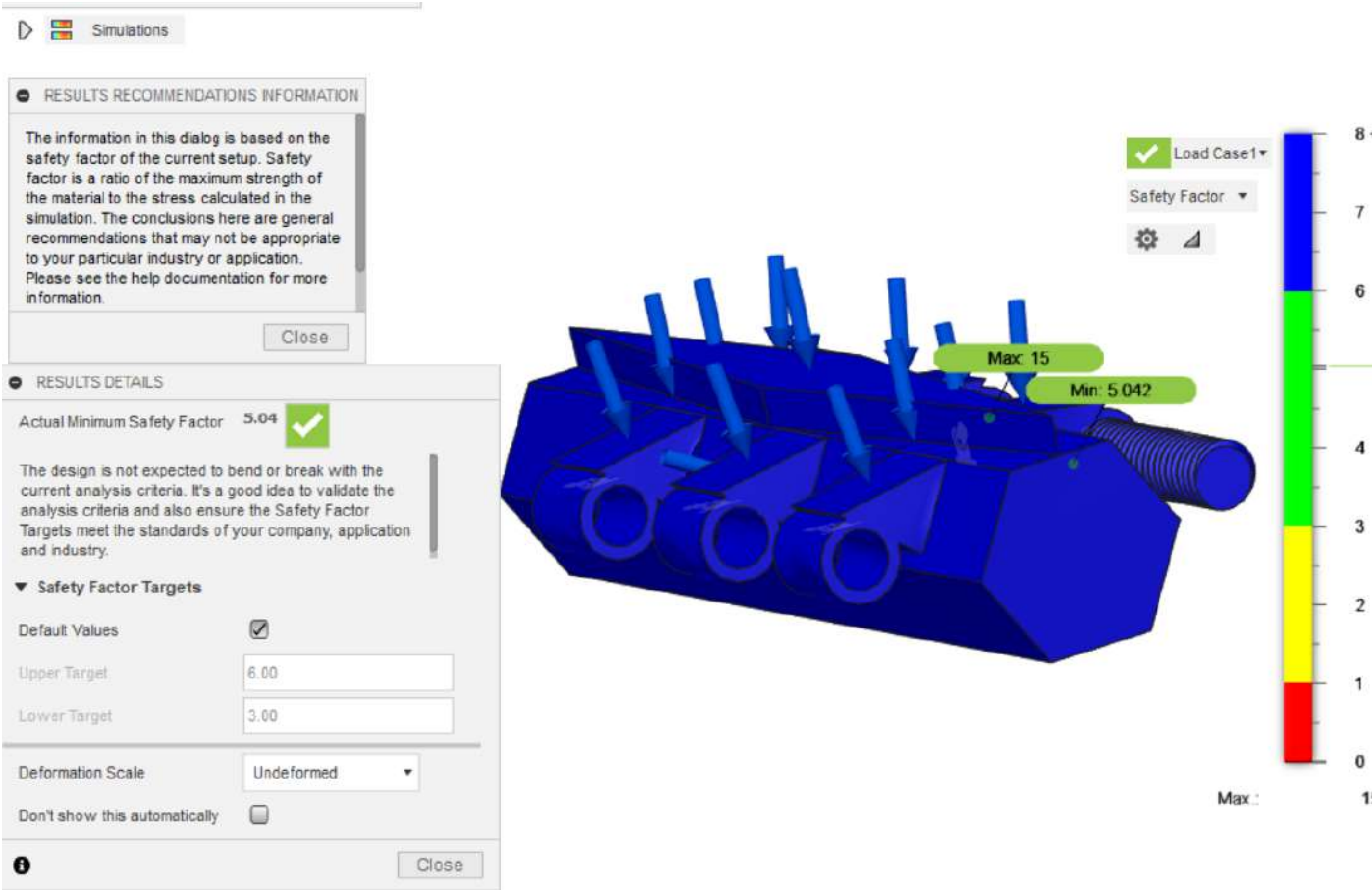


Figure 4.7: High Strength Structural Steel Safety Factor for 500N load

Inference: The solver data recommends the usage of this material for industrial manufacturing with a decent safety factor of 5.04 the belt link is not expected to bend or break and meets industrial criteria.

4.1.4 Case 4: Transient load of 500N on shock absorber

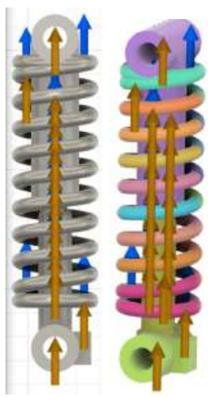


Figure 4.8: Transient Stress Load Analysis and Result

Result and Inference:The solver depicted the varied amount of stresses on different segments of shock absorber from this it can be inferred that the transient load is unequally distributed throughout the shock absorber causing negligible deformation due to spring action and it can endure 500N transient load.

4.2 Manipulator Simulation

Simulation of Joint Motion Angle and Manipulators Pick and Place operation was done using ROS, Rviz and Gazebo.

4.2.1 Case 1: Gripper/End Effector Motion

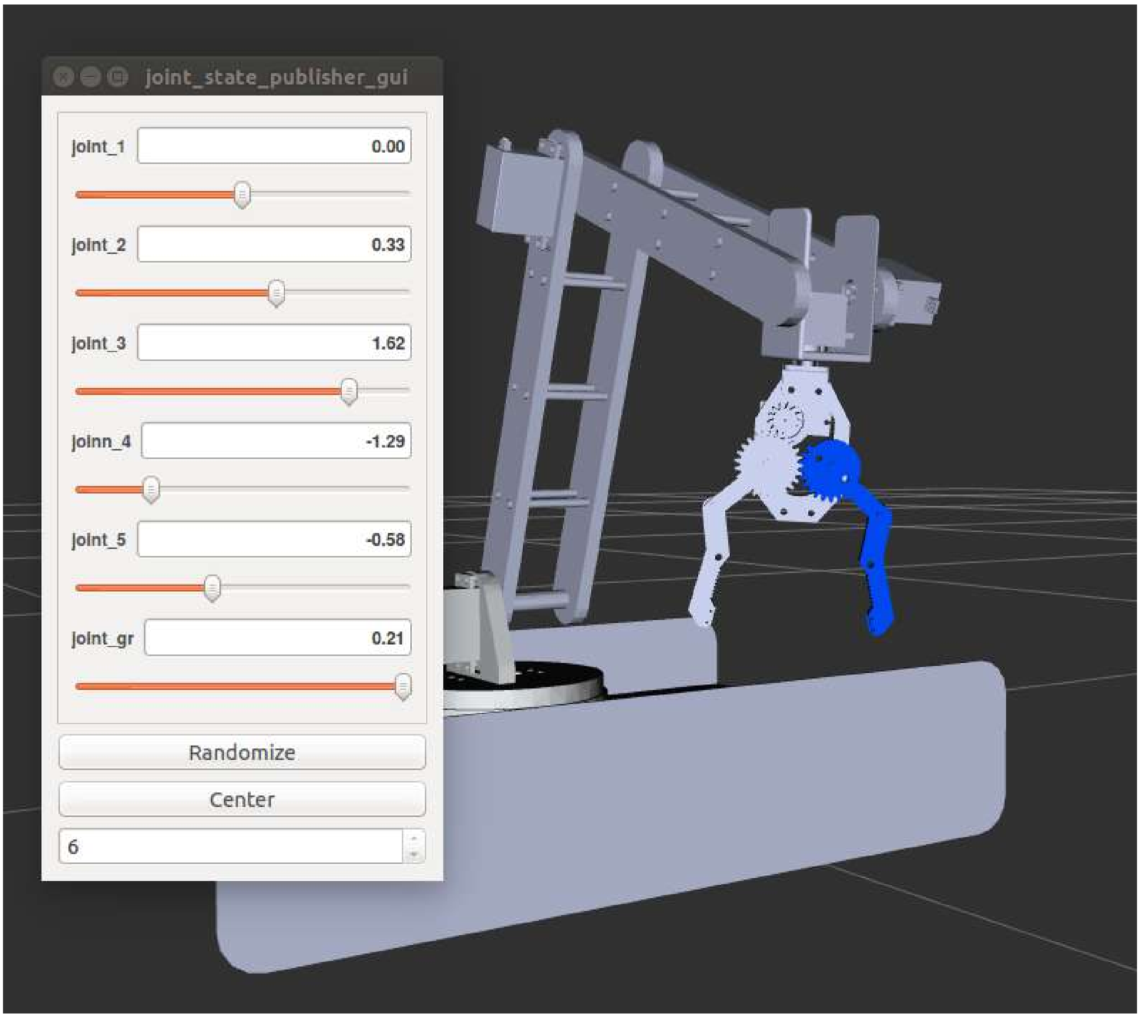


Figure 4.9: Gripper Open Motion Angle

Figure 4.10: Gripper Close Motion Angle

Result and Inference:The gripper responds to the GUI and has a open close range of 0.21 to -0.24 radians.

4.2.2 Case 2: Shoulder Joint

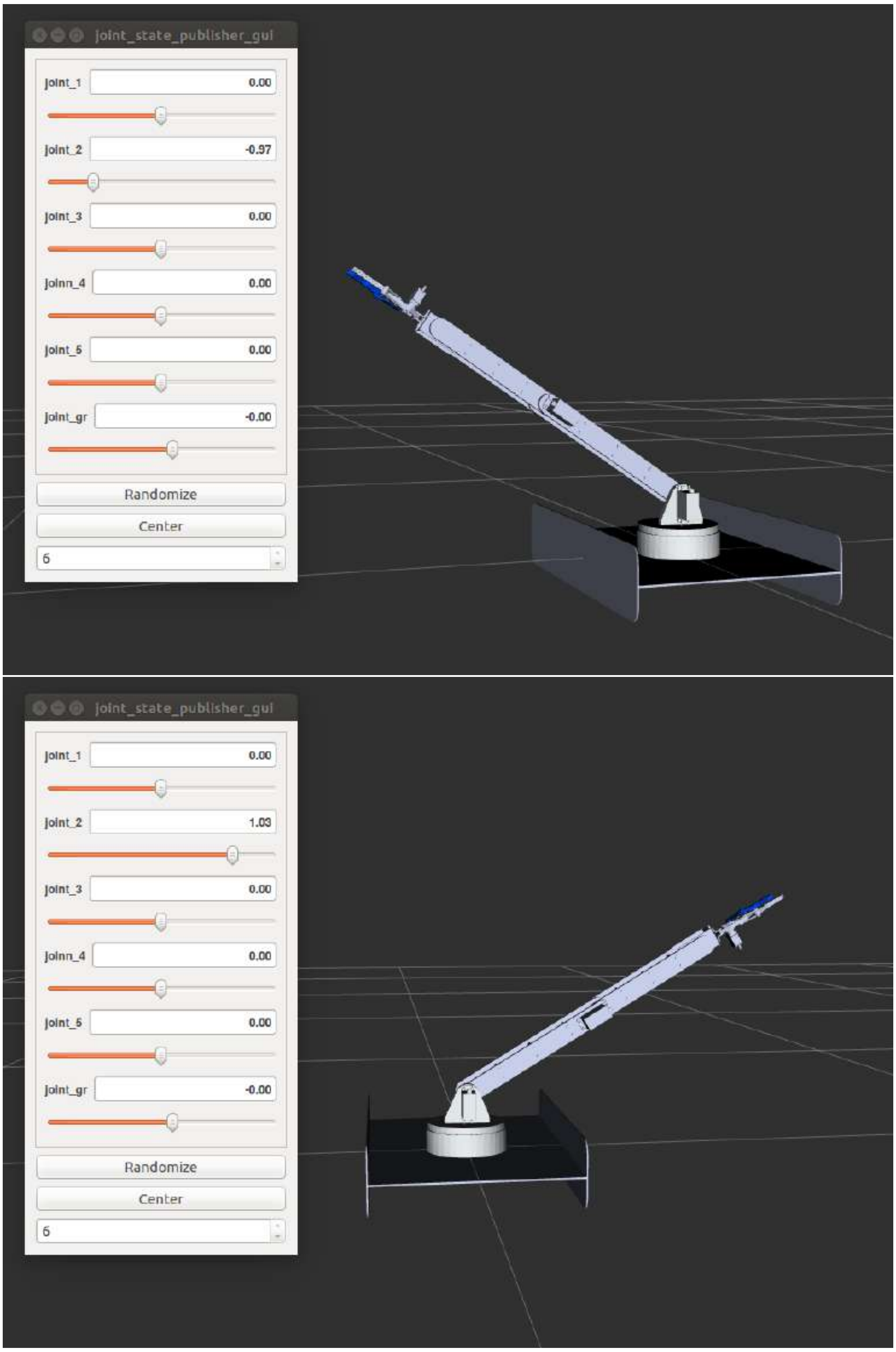


Figure 4.11: Shoulder Position 1 and 2

Result and Inference:The shoulder joint responds to the GUI and has a range from -1.2 to 1.2 radians.

4.2.3 Case 3: Elbow Joint

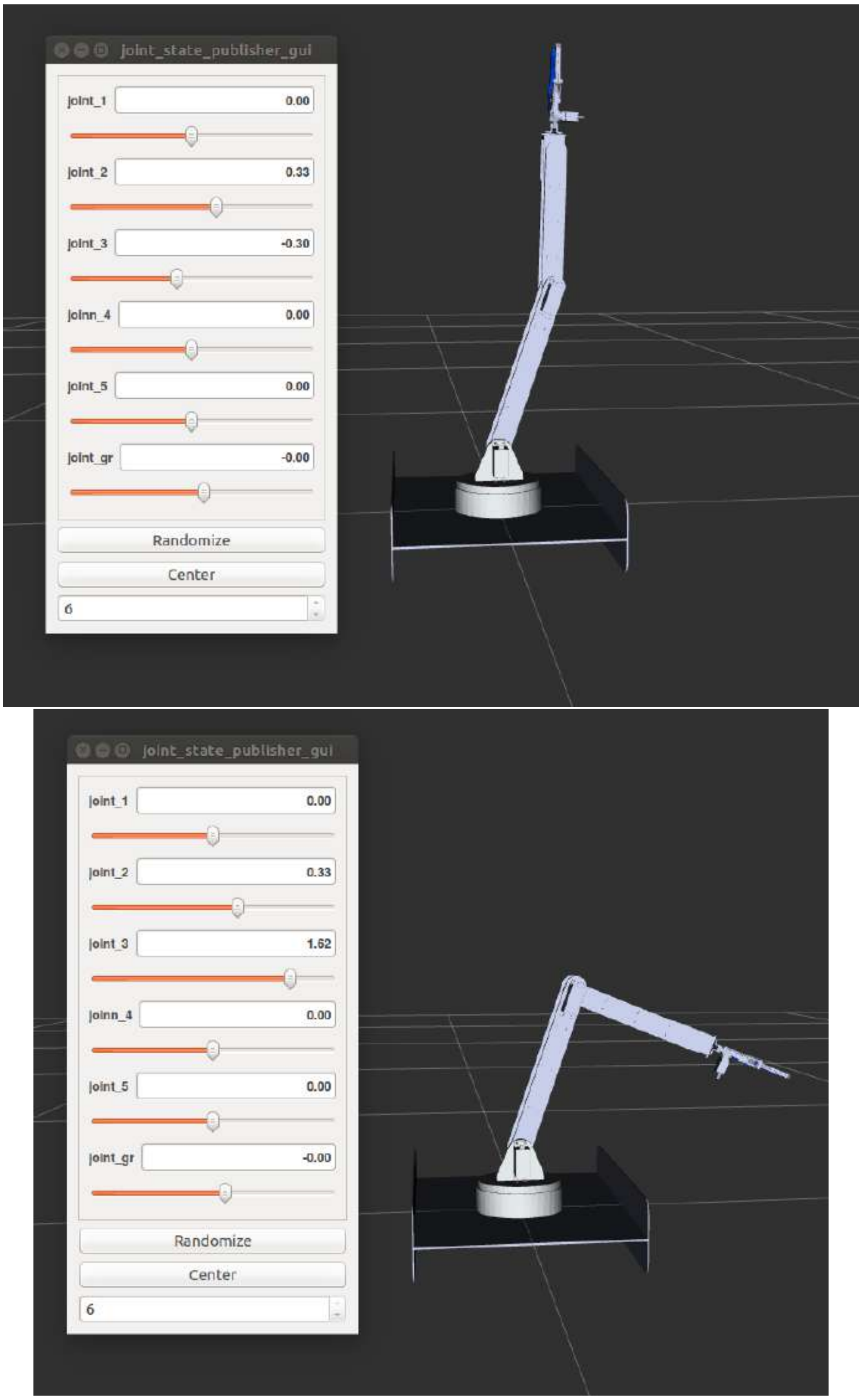


Figure 4.12: Elbow Position 1 and 2

Result and Inference:The elbow joint responds to the GUI and has a range from -1.3 to 1.6 radians.

4.2.4 Case 4: Wrist Pitch Motion

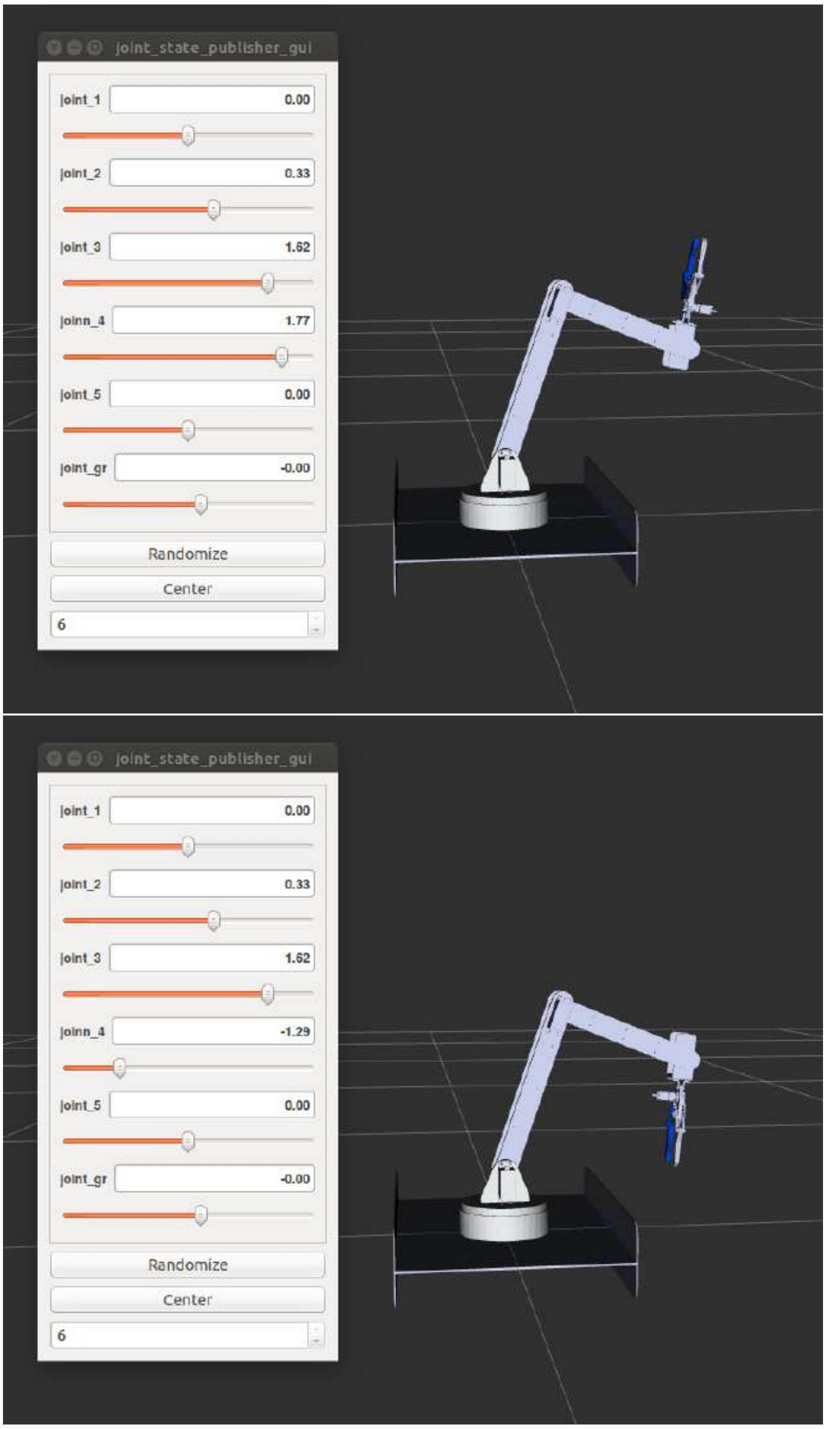


Figure 4.13: Wrist Pitch Motion Position 1 and 2

Result and Inference:The wrist responds to the GUI and has a pitch motion range from -1.29 to 1.77 radians

4.2.5 Case 5: Wrist Roll Motion

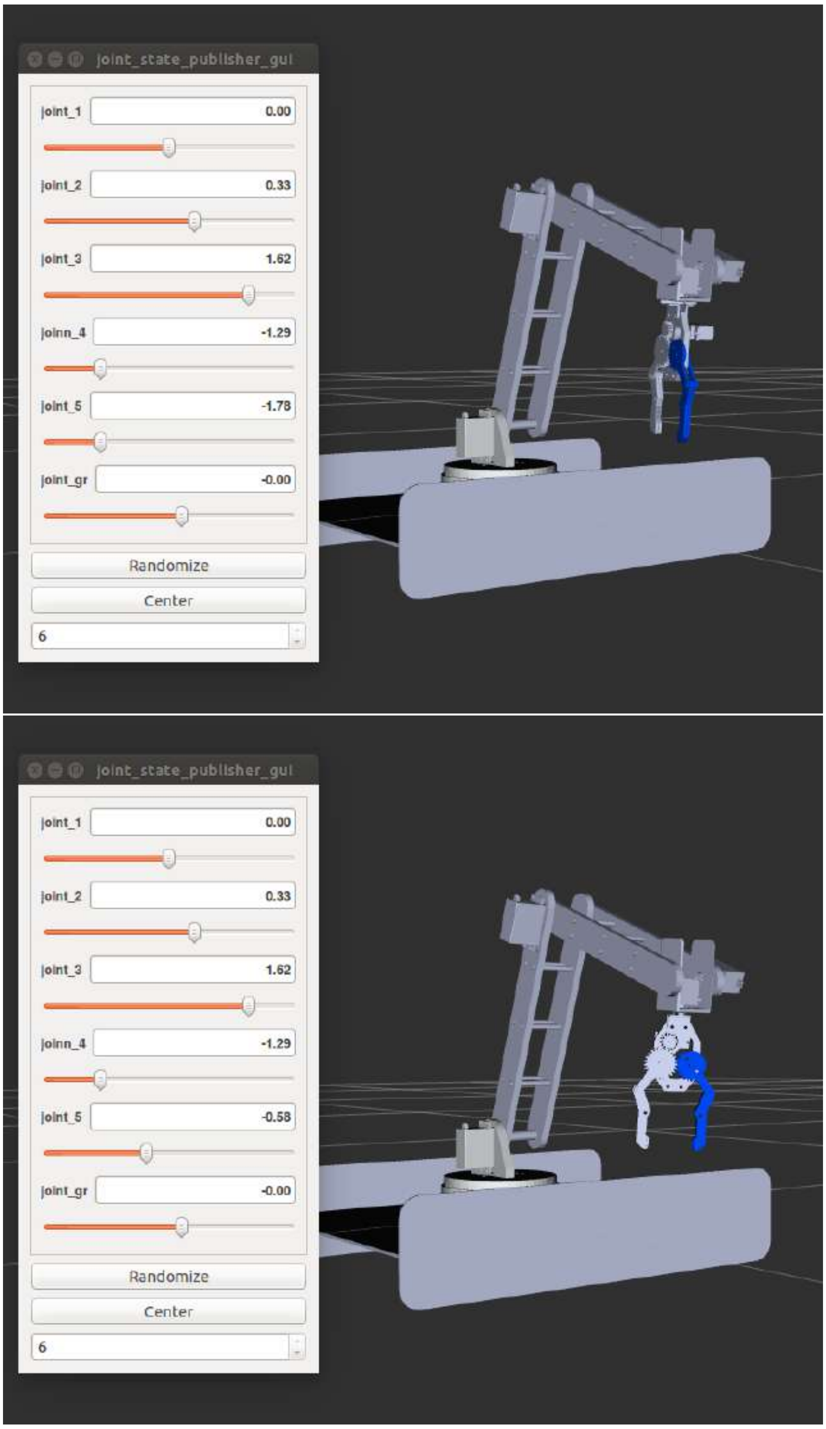


Figure 4.14: Wrist Roll Motion Position 1 and 2

Result and Inference:The wrist responds to the GUI and has a roll motion range from -0.58 to -1.78 radians

4.2.6 Case 6: Simulation of Pick and Place Operation

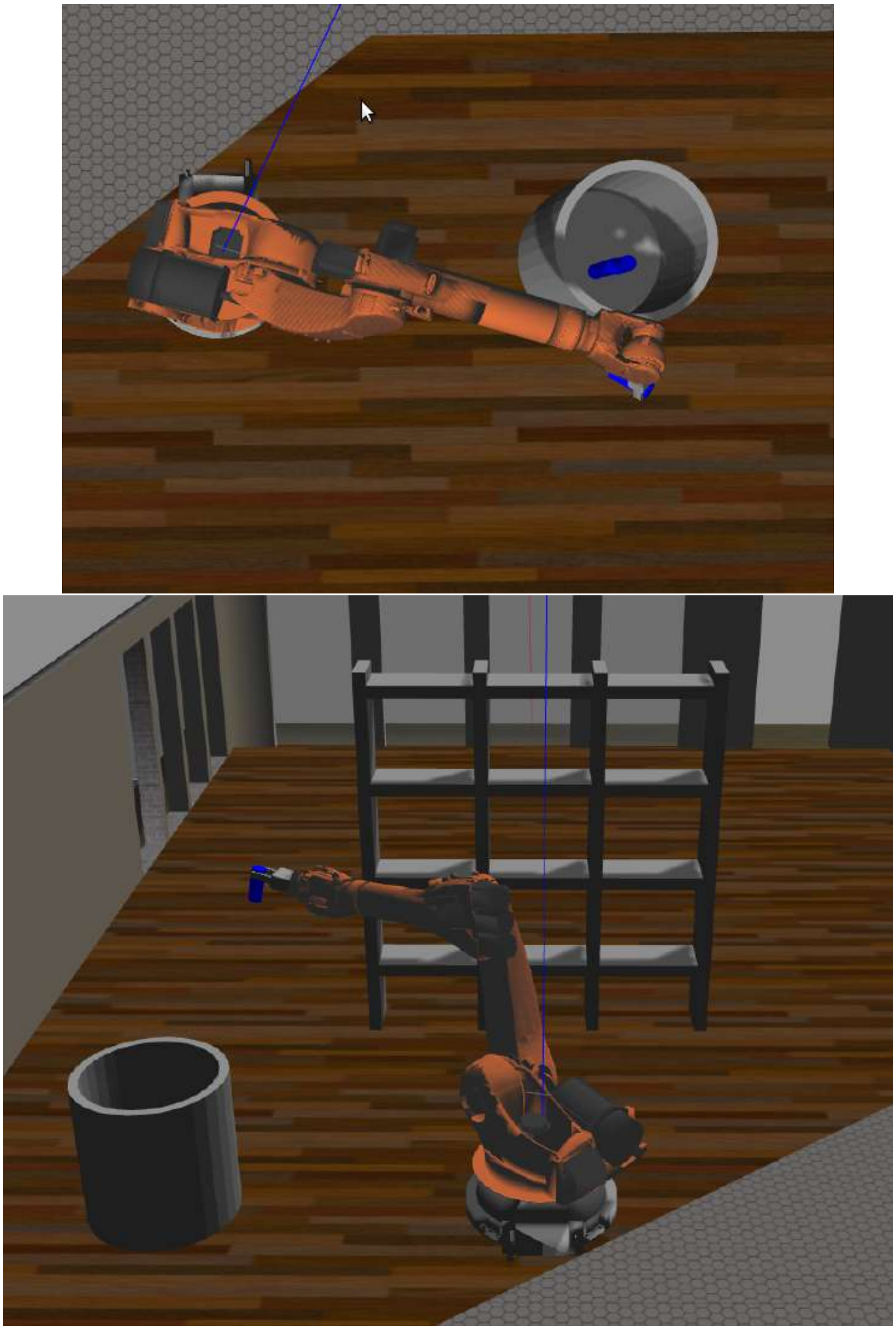


Figure 4.15: Top and Front View of Pick and Place Operation

Result and Inference: Successful Pick and Place operation was conducted in Gazebo with an object randomly placed on a shelf of 12 racks, it can be inferred that the manipulator accurately follows the designated path as well as all joints function as required.

4.3 Jammer Simulation

Jammer Circuit Simulations were done in NI Multisim by observing the waveforms generated by the circuits in an Oscilloscope model present within the software.The main purpose of the jammer is to produce random waveforms over the targeted frequency, which is the basis of our solution.[1][22]

4.3.1 Case 1: 450MHz Jammer Simulation

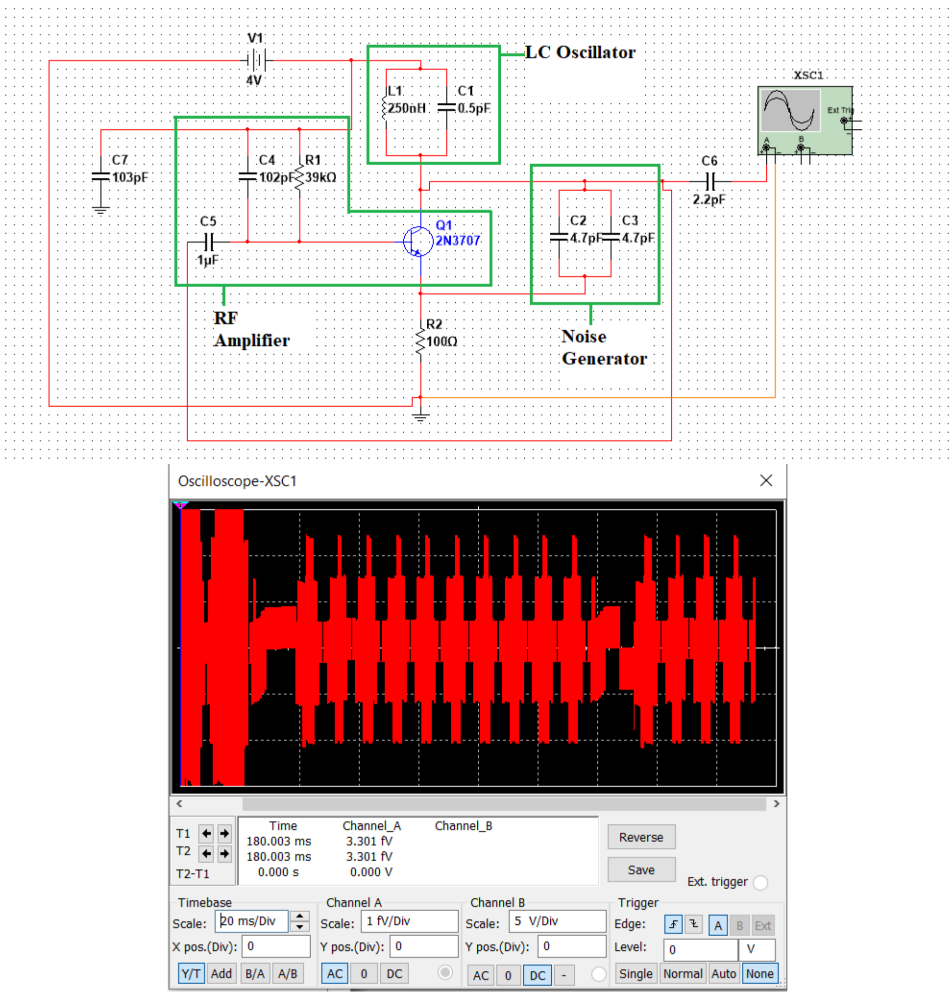
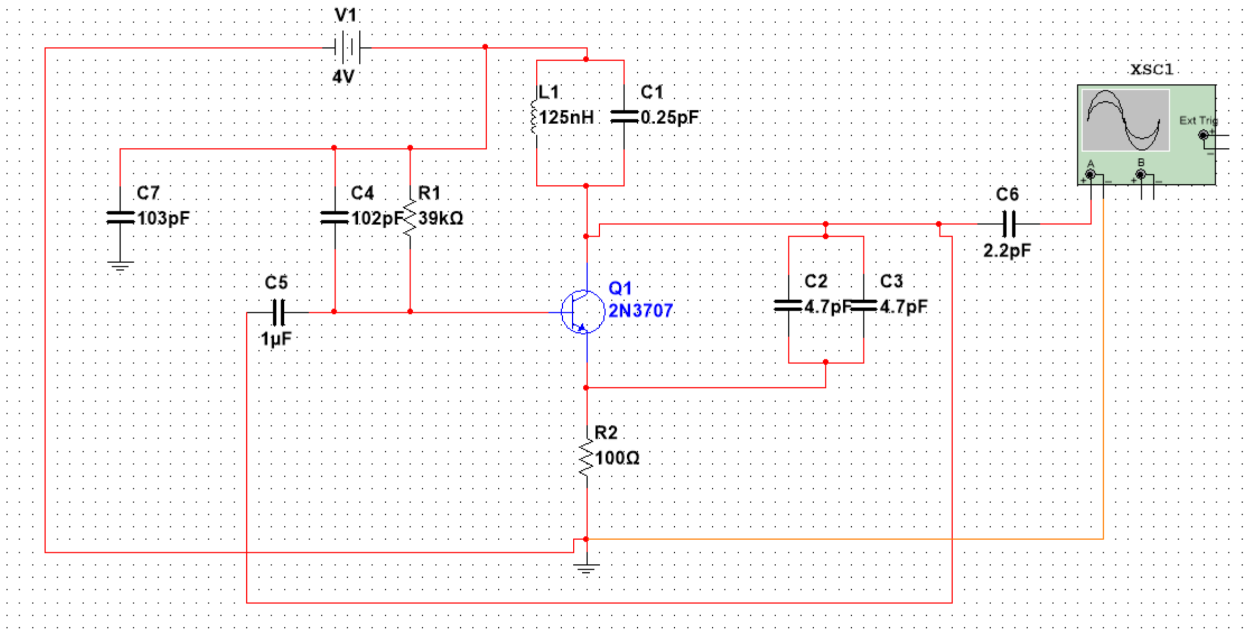


Figure 4.16: 450MHz jammer output waveform

Result and Inference:Random Output waveform is observed on the oscilloscope which shows that the circuit is operating as required and on a specific frequency of 450MHz sufficing the purpose of its design.

4.3.2 Case 2: 900MHz Jammer Simulation



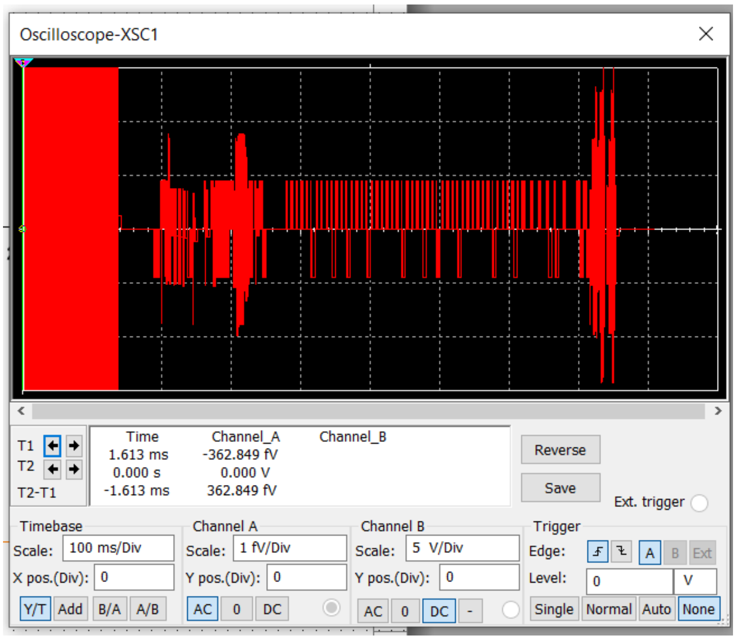


Figure 4.17: 900MHz jammer output waveform

Result and Inference:Random Output waveform is observed on the oscilloscope which shows that the circuit is operating as required and on a specific frequency of 900MHz which is characterized by thin and steep waveform which is a characteristic of high frequency or at least higher than 450MHz.

4.3.3 Case 3: 900MHz Hardware Jammer Testing

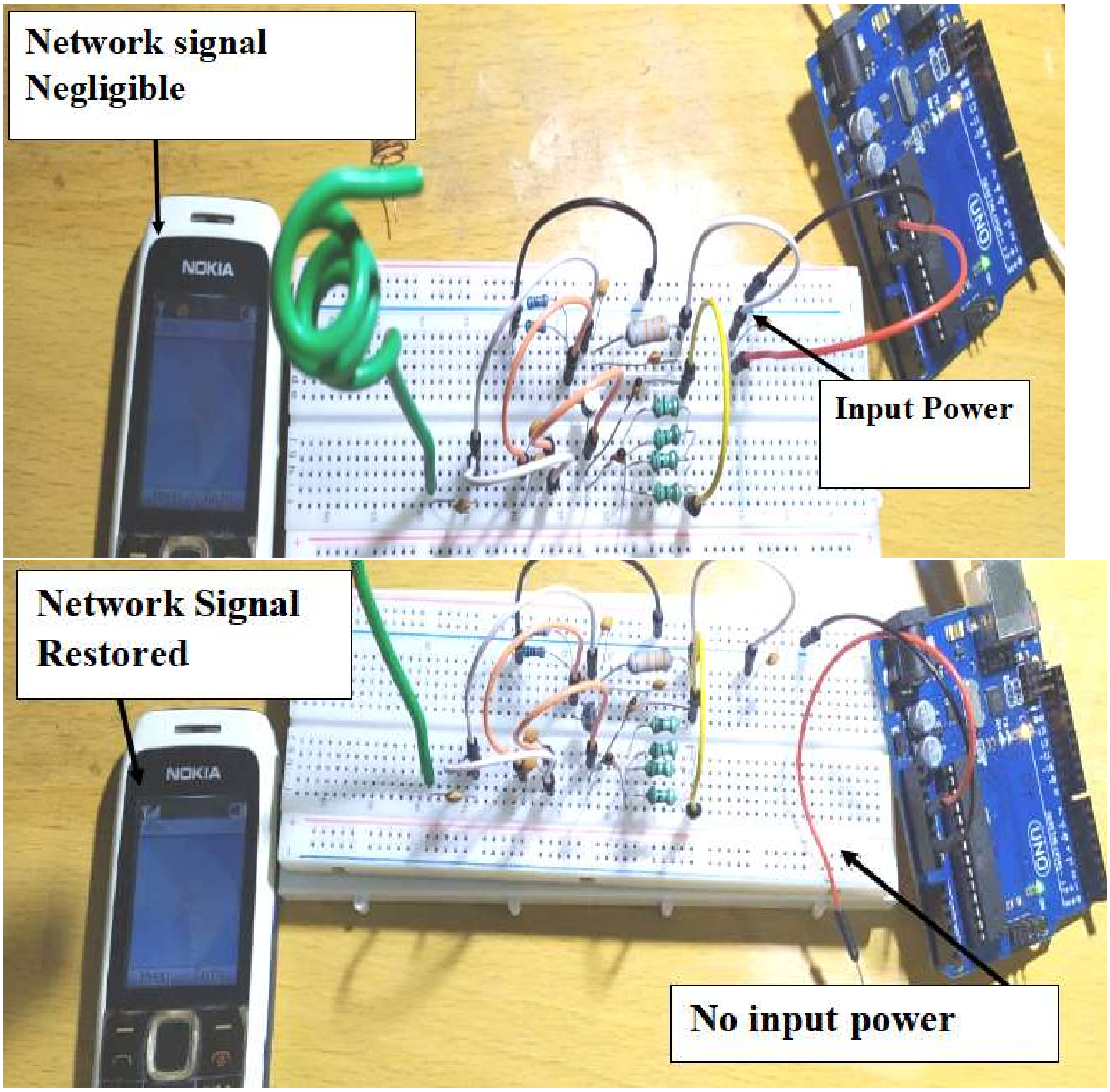


Figure 4.18: 900MHz Jammer ON and OFF State and its effect on mobile signal

Result and Inference:The network signal can be seen varying being in the vicinity of jammer, which shows that the jammer circuit is operational and successfully affects 900MHz GSM Band .

CHAPTER 5

CONCLUSION AND FUTURE ENHANCEMENT

1. According to our aim and problem statement we have eliminated the dependence on a 2 wheel drive mechanism by using a quad caterpillar tracks, which enhances the motion capability and survivability of the bot in tactical environments.

2. As per the results obtained in Chapter 4 section 1, we conclude that High Strength Structural Steel Material is optimum for building out robot as components made with this material can endure atleast 50Kg of stress without bending or breaking and is also economic thus making it ideal.

3. Detachable Manipulator with 6 Degrees of Freedom has definitely increased the robot reach.

4. While encountering a swamp surface the hydraulic piston helps the robot to adjust its structure by raising the chassis to efficiently have more ground clearance.

5. The on-board jammer module is frequency selective jammer thus does not interfere with robot and base station communication, in Chapter 4 section 3 we have achieved satisfactory results regarding the same.

6. At present these adjustments in the structure are made manually through a controller using RF communication which can be modified after proper testing and be made semi autonomous or even autonomous using certain sensors

7. This prototype can be implemented for vast area of exploration sciences and military purposes by replacing the current transceiver by a more efficient **Radio Frequency Technology** module with larger range of communication and also replacing servo motors by more efficient **stepper motors**

8. It can be made amphibious by protecting the housing cabinet and other modifications.

9. It can be made autonomous by feeding into GPS way-point pattern and using Artificial Intelligence.

10. In medical fields the bot can be modified into wheelchair designs.

11. In automobile industry , military vehicles.

REFERENCES

[1] Abdalla, A., Yuan, Z., Longdon, S. N., Bore, J. C., and Bin, T. (2015). "A study of eccm techniques and their performance." *2015 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*, 1–6.

[2] Al-Shehri, S. and Loskot, P. (2018). "Enhancing reliability of tactical manets by improving routing decisions." *Journal of Low Power Electronics and Applications*, 8, 49.

[3] Benren, T. (1994). "An eccm model and the technical development trends to the demands of the future ew combat." *IEEE Aerospace and Electronic Systems Magazine*, 9(6), 12–16.

[4] Fang, G., Matte, C.-D., Scharff, R., Kwok, T. H., and Wang, C. (2020). "Kinematics of soft robots by geometric computing." *IEEE Transactions on Robotics*, PP, 1–15.

[5] Fracchia, M., Benson, M., Kennedy, C., Convery, J., Poultney, A., Anderson, J. W., Tan, A., Wright, J., Ermilio, J., and Clayton, G. M. (2015). "Low-cost explosive ordnance disposal robot for deployment in southeast asia." *2015 IEEE Canada International Humanitarian Technology Conference (IHTC2015)*, 1–4.

[6] Harkins, R., Ward, J., Vaidyanathan, R., Boxerbaum, A. X., and Quinn, R. D. (2005). "Design of an autonomous amphibious robot for surf zone operations: part ii - hardware, control implementation and simulation." *Proceedings, 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics.*, 1465–1470.

[7] Hutchinson, S., Hager, G., and Corke, P. (1996). "A tutorial on visual servo control." *IEEE Transactions on Robotics and Automation*, 12(5), 651–670.

[8] Klein, G., Rogge, H., Schneider, F., Toelle, J., Jahnke, M., and Karsch, S. (2010). "Response initiation in distributed intrusion response systems for tactical manets." *2010 European Conference on Computer Network Defense*, 55–62.

[9] Koh, D. C., Dharmawan, A. G., Hariri, H. H., Soh, G. S., Foong, S., Bouffanais, R., Low, H. Y., and Wood, K. L. (2019). "Design and analysis of a miniature two-wheg climbing robot with robust internal and external transitioning capabilities." *2019 International Conference on Robotics and Automation (ICRA)*, IEEE, 9740–9746.

[10] Kousar, H., Atif, M., Ali, H., and Kundi, M. H. (2019). "Whegstr: A multiterrain robot with c-shaped whegs, implementation of error minimization technique and using artifical neural network (ann)." *2019 International Conference on Green and Human Information Technology (ICGHIT)*, IEEE, 139–141.

[11] KUZNETSOV, A. and OSETROV, O. (2006). "Detection of improvised explosives (ie) and explosive devices (ied)." *Detection and Disposal of Improvised Explosives*, H. Schubert and A. Kuznetsov, eds., Dordrecht, Springer Netherlands, 7–25.

[12] Lalitha, V. and Rajesh, R. (2013). "The impact of transmission power on the performance of manet routing protocols." *IOSR Journal of Engineering*, 03, 34–41.

[13] Nakajima, S. (2009). "Development of four-wheel-type mobile robot for rough terrain and verification of its fundamental capability of moving on rough terrain." *2008 IEEE International Conference on Robotics and Biomimetics*, IEEE, 1968–1973.

[14] Naskar, S., Das, S., Seth, A. K., and Nath, A. (2011). "Application of radio frequency controlled intelligent military robot in defense." *2011 International Conference on Communication Systems and Network Technologies*, 396–401.

[15] Oetomo, D., Daney, D., and Merlet, J.-P. (2009). "Design strategy of serial manipulators with certified constraint satisfaction." *Robotics, IEEE Transactions on*, 25, 1 – 11.

[16] Omijeh, B., Uhunmwangho, R., and Ehikhamenle, M. (2014). "Design analysis of a remote controlled pick and place robotic vehicle." *International Journal of Engineering Research and Development*, 10(5), 57–68.

[17] Sathiyanarayanan, M., Azharuddin, S., Kumar, S., and Khan, G. (2014). "Self controlled robot for military purpose." *International Journal for Technological Research in Engineering*, 1, 2347–4718.

[18] Schroer, R. T., Boggess, M. J., Bachmann, R. J., Quinn, R. D., and Ritzmann, R. E. (2004). "Comparing cockroach and whegs robot body motions." *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA '04. 2004*, Vol. 4, 3288–3293 Vol.4.

[19] SCHUBERT, H. (2006). "Disposal of improvised explosives and -devices." *Detection and Disposal of Improvised Explosives*, H. Schubert and A. Kuznetsov, eds., Dordrecht, Springer Netherlands, 1–6.

[20] Shirafuji, S. and Ota, J. (2019). "Kinematic synthesis of a serial robotic manipulator by using generalized differential inverse kinematics." *IEEE Transactions on Robotics*, 35(4), 1047–1054.

[21] Simon, P. (2015). "Military robotics: Latest trends and spatial grasp solutions." *International Journal of Advanced Research in Artificial Intelligence*, 4.

[22] Voth, D. (2004). "A new generation of military robots." *IEEE Intelligent Systems*, 19(4), 2–3.

[23] Ward, J. L. (2005). "Design of a prototype autonomous amphibious whegs robot for surf-zone operations." Ph.D. thesis, Monterey, California. Naval Postgraduate School, Monterey, California. Naval Postgraduate School.

[24] Watson, J. T., Ritzmann, R. E., Zill, S. N., and Pollack, A. J. (2002). "Control of obstacle climbing in the cockroach, blaberus discoidalis. i. kinematics." *Journal of Comparative Physiology A*, 188(1), 39–53.

[25] Weihmann, T., Brun, P.-G., and Pycroft, E. (2017). "Speed dependent phase shifts and gait changes in cockroaches running on substrates of different slipperiness." *Frontiers in zoology*, 14(1), 54.

[26] Wile, G. D., Daltorio, K. A., Palmer, L. R., Witushynsky, T. C., Southard, L., Ahmad, M. R., Malek, A. A., Gorb, S. N., Boxerbaum, A. S., Ritzmann, R. E., and Quinn, R. D. (2008). "Making orthogonal transitions with climbing mini-whegs." *2008 IEEE International Conference on Robotics and Automation*, 1775–1776.

[27] Zhao, H. (2008). "Simulation of barrage-type jamming for synthetic aperture radars." Vol. 2, 462 – 465 (09).