INDIAN INSTITUTE OF TECHNOLOGY, PATNA

Inter IIT Tech Meet 8.0

IIT Roorkee • 20-22 December 2019

FULL REPORT

DIC'S

TERRACE FARMING ROBOT FOR HILLY AREAS

PROBLEM STATEMENT

The teams are required to develop a lightweight robot that can do the work of ploughing, seeding, watering, or harvesting considering the above-mentioned challenges for terrace farming. The robot should be able to perform at least one of the above-mentioned processes and able to climb up and down through the steps of terrace farming. Teams are required to produce a reliable navigation plan of the robot for autonomous navigation in the field. Teams need to develop a technology-driven solution for them and demonstrate the prototype/proof of Concept in action during the 8th Inter IIT Tech Meet at IIT Roorkee.

INTRODUCTION

Tracing back through times, we observe how to terrace cultivation is an excellent example of living cultural landscape evolution. Works of Historians and Geologists have confirmed that terrace farming system has been in practice for about 300–500 years in Tanzania, 2,000 years in Peru, Guatemala and Mexico, approximately 3,000 years in Cyprus, about 4,500 years in China and for the past 5,000–6,000 years in Yemen. Increasing the productivity of the land available is an essential element to meet the ever-increasing food and forage demands in hillside and mountain communities due to factors like overpopulation. To achieve this, it is necessary for the farmers to not only have access to an adequate amount of land, and manure but also to possess affordable, effective and efficient farm tools required to increase crop yields. Doing so would increase the per hectare crop productivity of arable land. Mechanizing the whole farming process would also mean that a larger quantity of land can be made into terraces and increase the farm sizes to meet the demands. In turn, this would increase the per capita productivity of the farmers, which will lead to a heightened income and thence a total economic growth of the community.

Keeping all of these in our mind, we have fine-tuned the multifold parameters of our project as designing an innovative, low-cost robot prototype that is well-equipped with features that can overcome the harsh agronomic challenges faced in the terrace farming practice, hence intensifying the aforementioned means of agriculture. The challenges of automation and mechanization in terrace farming include the unpredictable nature of the terrain, looseness, and instability of the soil, high rugged topography of the terraces and illiteracy of the farmers, all of which would be discussed in the further section.

SURVEY ANALYSIS

After studying the terrace farming practices of various parts of the country and analyzing state of art techniques, we identified the following problems:

- *Height of steps:* Clearly, the first problem to overcome was locomotion - coming up with a simple yet effective climbing mechanism that is robust enough to carry the weight of bot and tools attached, with sufficient speeds. The cost associated was considered to make out bot a viable option to the multifold.
- *Variation in step heights:* In most target areas, it is seen that step size (length and height) varies unpredictably. Hence, the bot must be capable of detecting the alterations and perform the operations accordingly. This problem was taken care of by incorporating positioning and measurement sensors.
- *Looseness of terrains:* Since the nature of the soil is loose in the target areas, the locomotion system was to be designed keeping the hindrance in mind. Thought was also put into the point that the bot locomotion of bot should not be damaging the existing plantation.
- *Illiteracy of the farmers:* A farmer cannot be expected to have excellent proficiency it operating a complicated digital contraption; hence we will have to come with a fool-proof and in genuine setup which would be operable by people with a minimal learning curve.
- *Shortcomings of existing solutions:* Most states of art techniques and solutions are expensive and require substantial human inputs. As the majority of the farmers only have access to small farmland, this is the main reason why their semi-automation is relatively inviable. For them, such an investment would be impractical as they would still have extended efforts even after the purchase of the solution.

All of these factors make conventionally designed hard-coded robotic agricultural solution inviable. We have given an unorthodox approach to this problem statement by designing a distinctive robot model that is fully automated and is capable of accomplishing everyday tasks in such rugged terrains with ease, with minimal human input.

The model is capable of sowing and plowing operations in any soil conditions (rough/loose) and is completely automated. The only human input currently required is the filling of seeds inside the tank, which can be overcome by manufacturing a docking station for the bot.

SOLUTION APPROACH

#CLIMBING MECHANISM:

The *'climbing-up'* motion of the bot is explained in detail

i. The ultrasonic sensor at the front senses the wall, this activates the front lift mechanism. The motors make the forward part of bot slide on the frame so that it reaches the upper step.

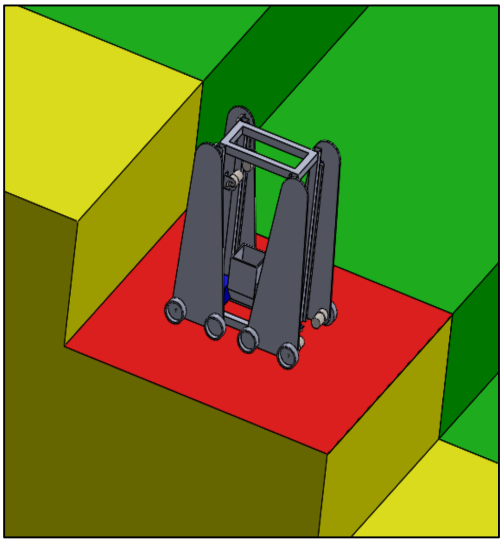
ii. Now the bot moves forwards until the wheels of the front frame touch the above step. The sensor on the lower part ensure that the wheels have landed on the step.

iii. Chassis frame starts coming up by the motor actuated rack until the height of the lower point of tyres is equal to the height of the step.

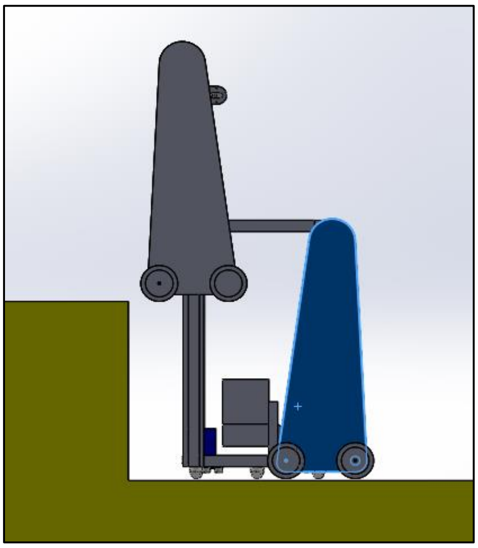
iv. The rear-wheels initiate motion in the forward direction until the chassis frame rests completely on the upper step.

v. Now, the rear frame is at the lower step hence the rear frame will be brought to the upper step using motor actuated rack.

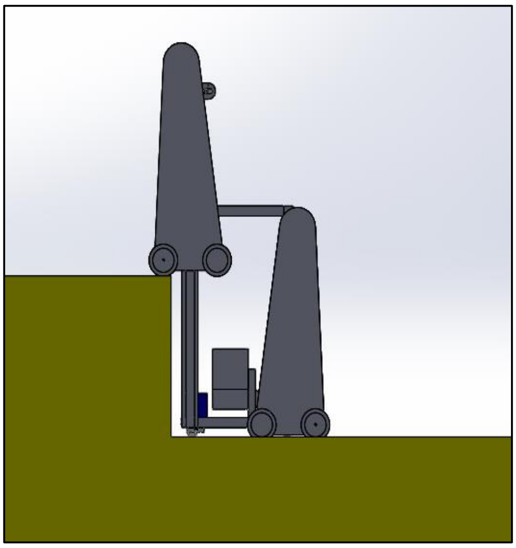
Similarly, the configurations in reverse order are followed for *'climbing-down'*.



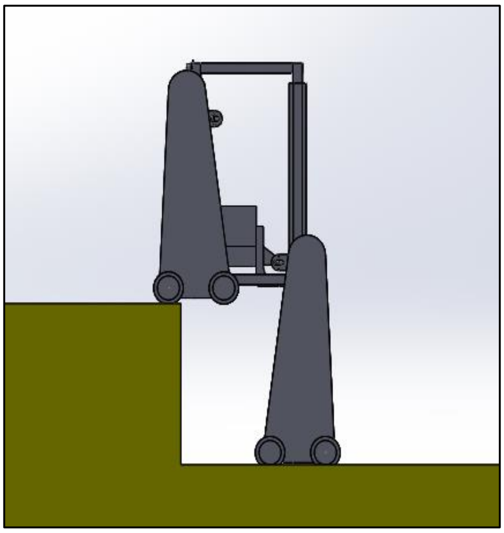
Configuration 1: The sensors detect the wall and align the bot



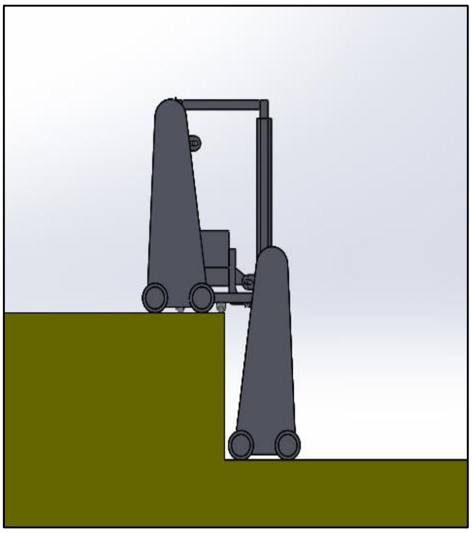
Configuration 2: The sensors detect a wall and align the bot.



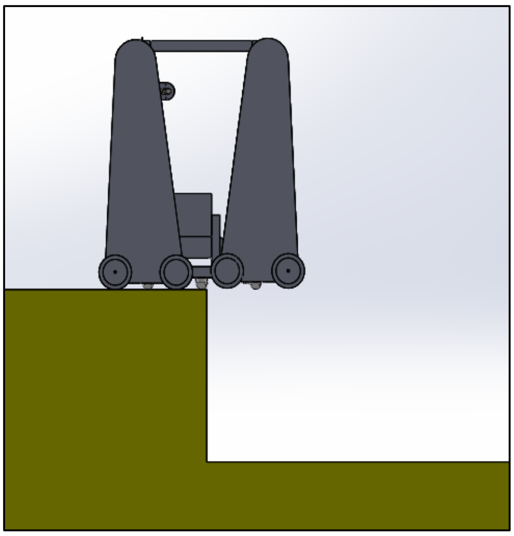
Configuration 3: The bot propagates so that the front-wheels land upper step.



Configuration 4: Rack and hence the chassis is pulled up along the slider.



Configuration 5: The bot propagates so that weight shifts on upper step.



Configuration 6: Finally, the rear part also climbs along the rack.

Figure 1: Various configurations in climbing up mechanism.

#HORIZONTAL MOVEMENT:

The algorithm for horizontal motion is made considering the fact that step size may vary in a field. Ultrasonic sensors are used to take care of that, thus providing a low-cost and light solution than most positioning and alignment sensors.

- When the bot climbs up, it rotates 90° clockwise and ultrasonic sensors aligns it parallel to the step.
- The bot moves forward until the ultrasonic sensor at the bottom detects an abrupt change, which marks the end of step.
- Now it turns around and traverses in straight line until it detects the other end of the step.
- This cycle continues until the top sensors detects a wall. The bot then goes for a last time on the step. Perform the operation on the specific line.
- Then it turns back and reach the starting position where the climbing mechanism is activated and the cycle continues.

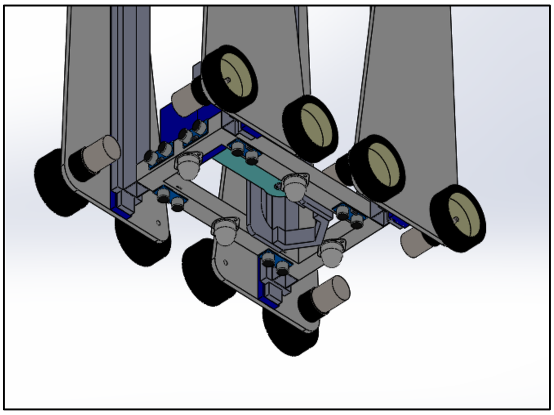
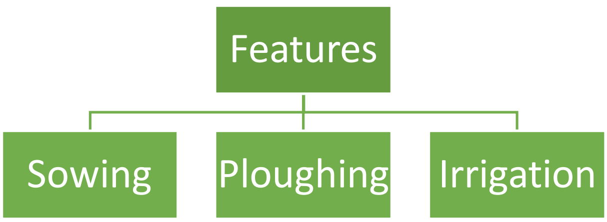


Figure 2: Bottom view of the bot, with ultrasonic sensors pointing downwards.

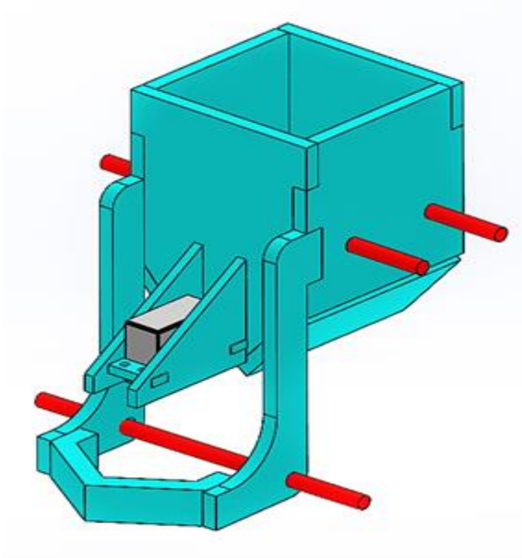
#FEATURES:

In order to provide multi-functionality, still keeping the weight and cost low we came up with the module approach.

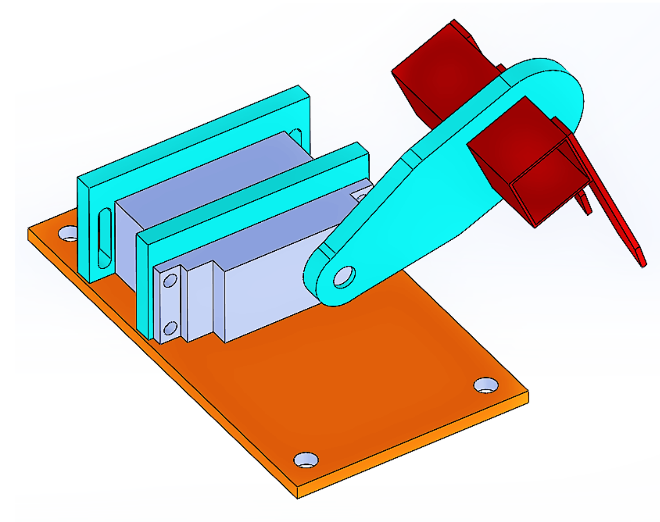
The modules can be attached and detached as per the purpose required thus reducing load and at the same time increasing functionality.



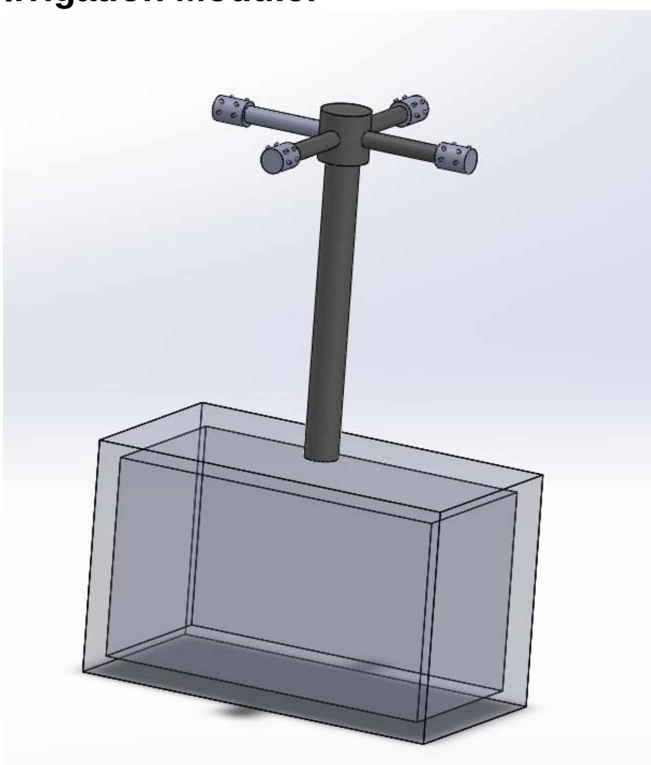
Sowing Module:



Ploughing Module:



Irrigation Module:



COMPONENTS OF BOT

#CHASSIS:

The chassis comprises of the aluminum frame.
Weight: 1.80 kg
Manufacturing: For prototyping the manufacturing was done by bolting aluminum square tubes to form the required shape. Mass manufacturing of the chassis is feasible by replacing the bolts with TIG welding thereby decreasing the weight.
Material: Aluminum

#FLAPS:

The flaps made of acrylic not only serve the purpose of lifting but also serve as the locomotion system of the bot.
Weight: 0.2 kg (each)
Material: Acrylic sheet 8 mm thickness
Manufacturing: The acrylic was cut on CO_2 laser cut to ensure precision in manufacturing.

#RACK AND PINION:

Made of steel, the four gear systems placed in the flaps serve the task of lifting.
Weight: 0.6 kg (each pair)
Material: S45C Stainless Steel
Manufacturing: The S45C was machined in a rack cutter with module 2. The it was processed for carburization. This process can be implemented for mass manufacturing also. The gear was made on a wire cut EDM, although it can be made by gear hobbing for mass manufacturing thus saving a lot of cost.

#SLIDER:

The slider serves as a major component of the lifting mechanism. It helps in swift movement of rack along the flaps.
Weight: 0.2 kg (each)
Material: Stainless steel
Manufacturing: The slider is better procured from a third party, for its manufacturing involves a lot of complex steps and it's easily available.

#MOTORS:

There are four motors of 10 RPM for lifting mechanism and four motors of 30 RPM for locomotion. *Weight:* 0.180 kg (each)

#SENSORS:

The whole task of automation was done by using only 7 ultrasonic sensors. This was done to ensure that we don't over-engineer the bot thereby adding some features which farmers find difficult to comprehend, thus reducing the cost of bot.
Weight: 0.05 kg (each)

#CONTROLLER:

Arduino along with motor drivers suffice all our controlling needs. Thereby reducing the cost of the bot and making it optimize for the task.
Weight: 0.3 kg (Total)

#MOUNTINGS:

It includes couplers and clamps used for holding the motors and pinion in place. They were purchased as per the specification of the motor and pinion.
Weight: 0.1 kg (each)

Component	Manufacture /Procured	Quantity	Total Weight (kg)
Chassis	Manufacture	1	1.8
Flaps	Manufacture (precision required)	4	0.8
Rack	Manufacture	4	1.6
Pinion	Manufacture (precision)	4	0.8
Slider	Procured	4	0.8
Motors	Procured	8	1.6
Sensors	Procured	8	0.4
Controller	Procured	-	0.3
Mounting	Procured	8	0.8
Total			8.9

SPECIFICATIONS OF BOT

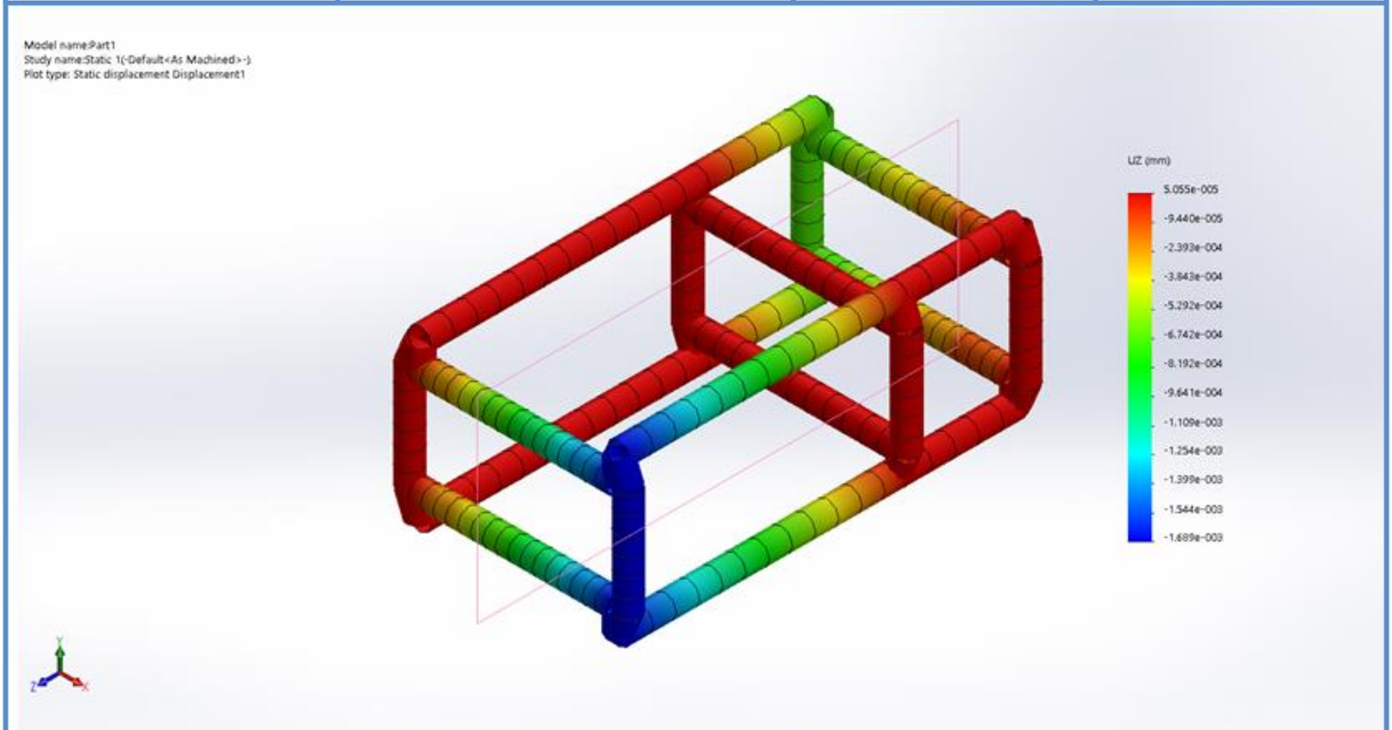
Weight	**8.9 kg**
Dimensions (L x B x H)	505 x 440 x 610 mm

ENGINEERING ANALYSIS

#CHASSIS ANALYSIS:

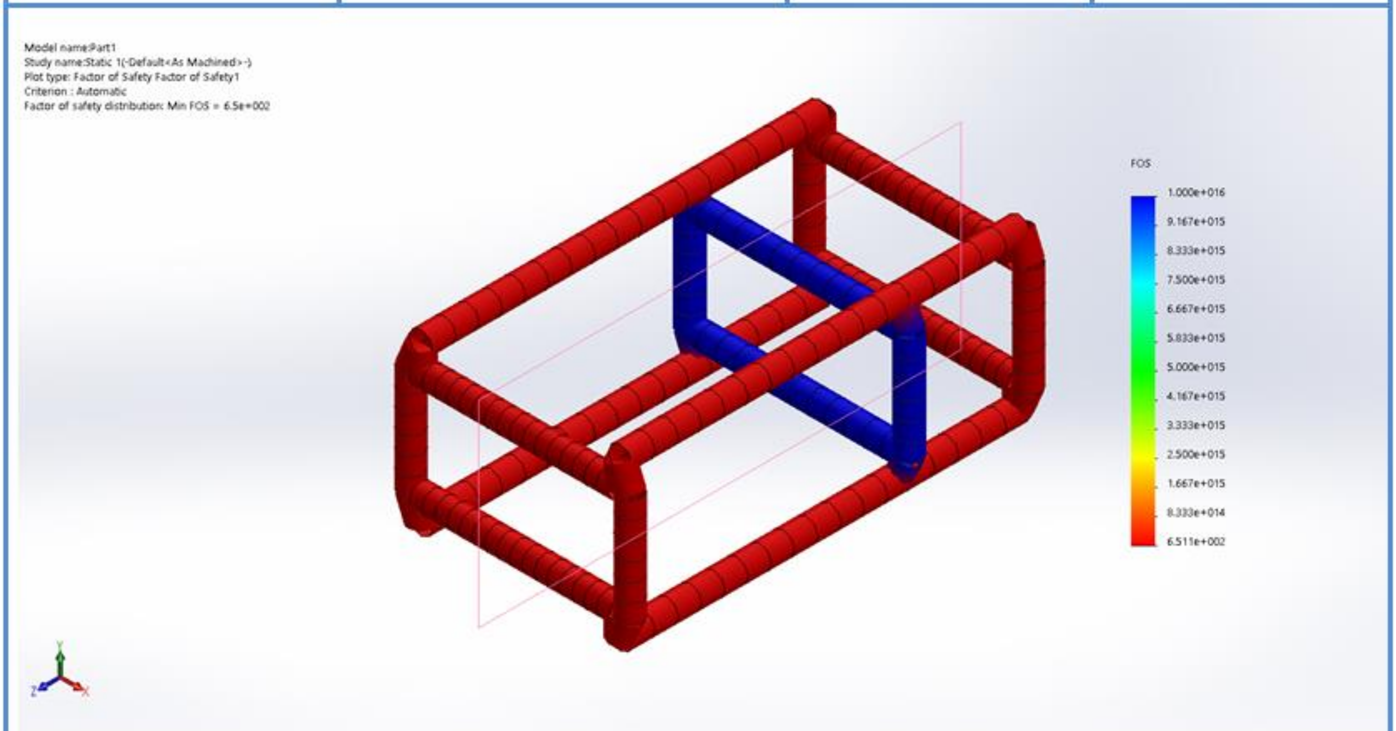
The analysis was done on ANSYS, considering aluminium material and applying tensile load and moment

Name	Type	Min	Max
Displacement1	UZ: Z Displacement	-1.689e-003mm Node: 35	5.055e-005mm Node: 15



Part1-Static 1-Displacement-Displacement1

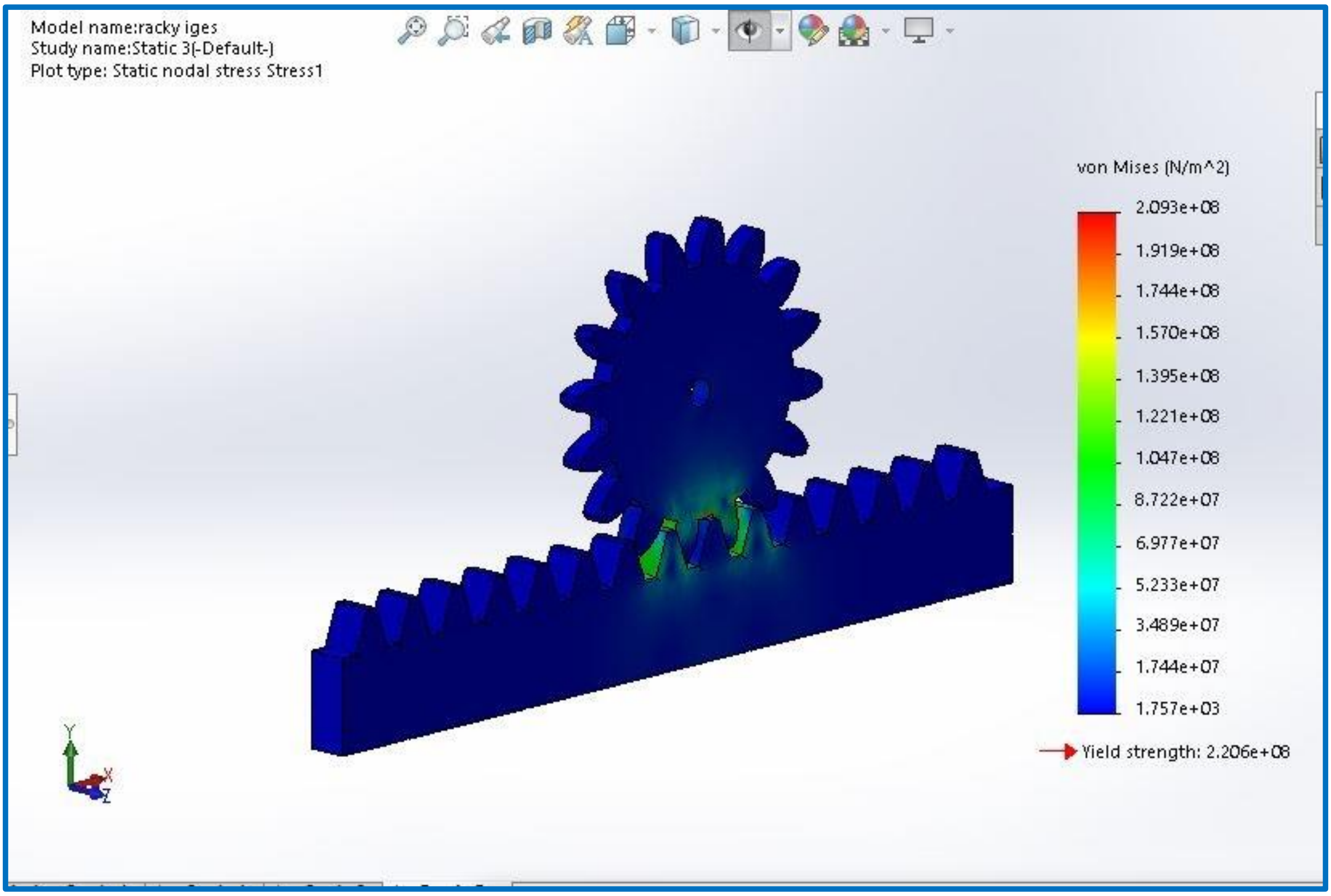
Name	Type	Min	Max
Factor of Safety1	Automatic	6.511e+002 Node: 141	1.000e+016 Node: 22

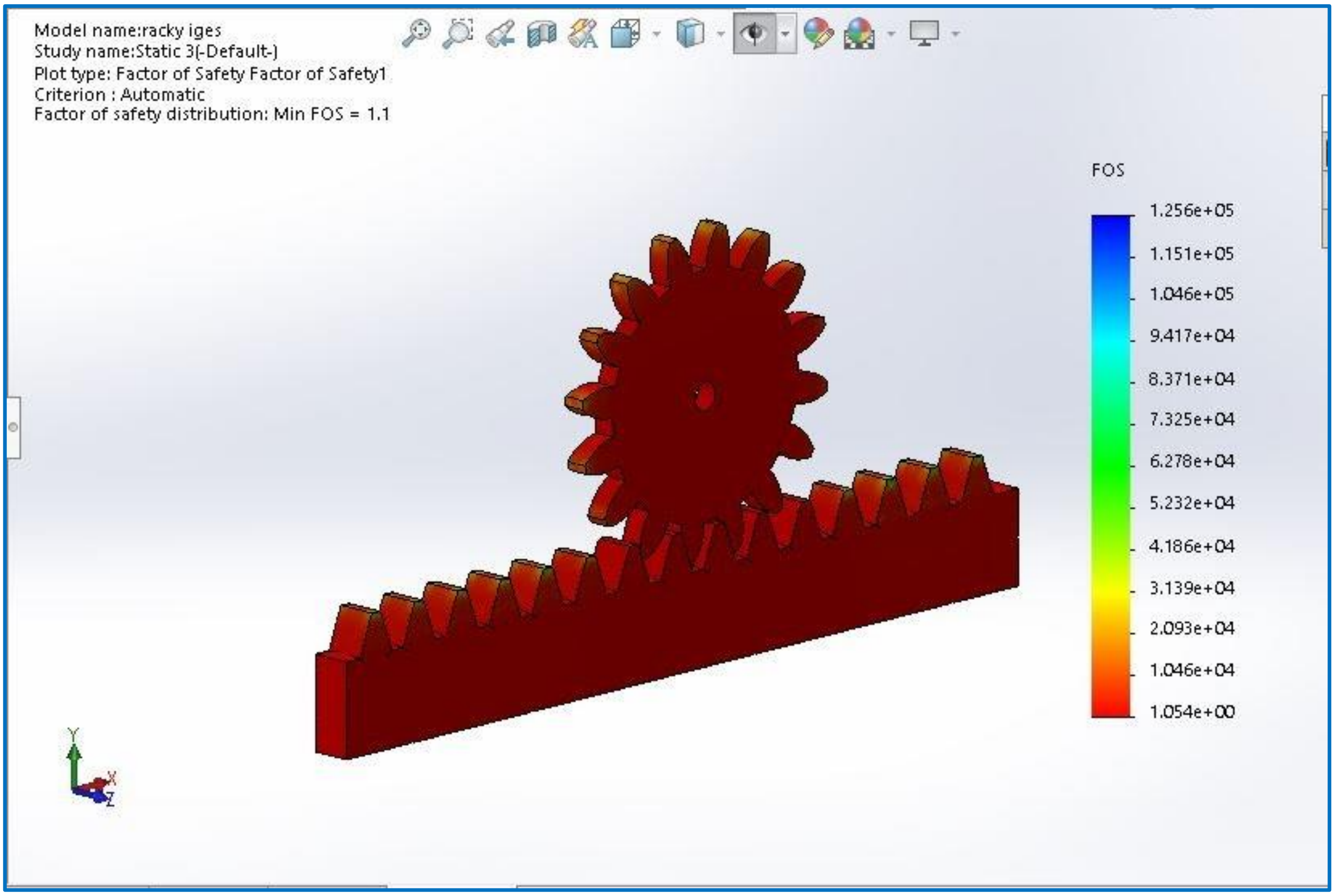


Part1-Static 1-Factor of Safety-Factor of Safety1

#RACK AND PINION

Mesh analysis of rack and pinion was performed considering load of the weight of the bot.



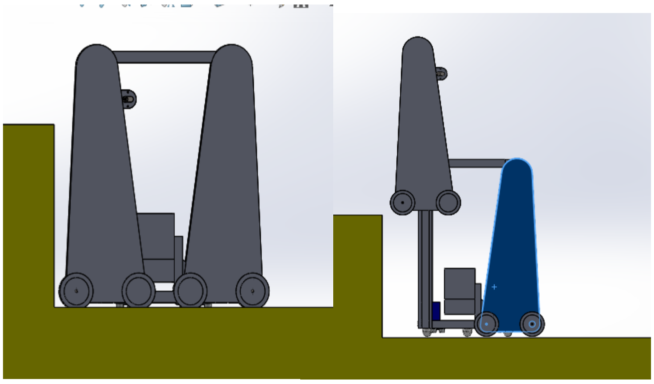


TORQUE CALCULATION

#LIFTING MOTORS

CASE 1:

Motor torque calculation when only the front two flaps are moving upward



Weight of each flap = 0.66 kg
Radius of each pinion = 32 mm
Torque = 0.66 kg x 32 mm
= 21 Kgmm = 2.1 Kgcm
{assuming 100% efficiency}

Each step reduces the total efficiency by their respective percentage, so the total efficiency

- Battery -> Motor Controller: 95% efficient
- Motor Controller -> Motors: 96% efficient
- Brushed DC motor: 92% efficient
- Spur gear (each stage): 93% each stage (estimate 5 stages)

This brings us to a 58% percent maximum efficiency
Torque = 2.1 x (100/58) kg-cm
= **3.620 Kg-cm** {for 58% efficiency}

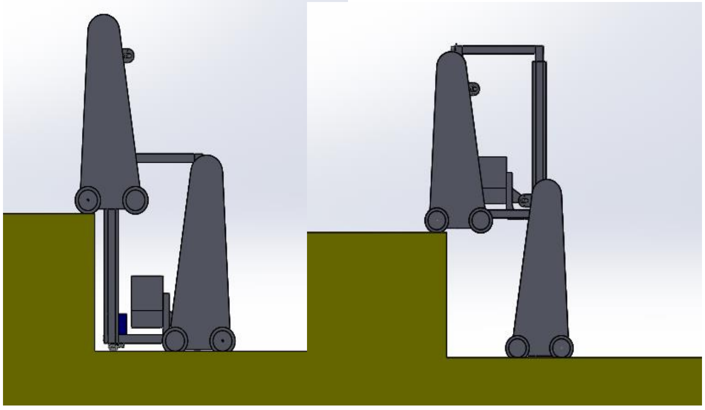
CASE 2:

Motor torque calculation when all the middle frame is moving upward

Weight of middle frame = 5.464kg
The radius of each pinion = 32 mm

N = *number of motors* = 4
Torque = 5.46 kg x 32 mm/N
= 17.472/N kg-cm
= 4.368 Kg-cm {assuming 100% efficiency}

Torque = 4.368 x (100/58) kg-cm
=**7.53103 Kg-cm** {for 58% efficiency}



Selected Motor Specification:
Rated torque = 40 kg-cm
Motor Speed = 10 RPM

#LOCOMOTION MOTORS

T = fr *R
fr = m*a
T = m*R*a
For four base motors and with e % efficiency
T = (m/4)*R*a *(100/e)

Angular speed = 30 RPM = 3.14 rad/s
Acceleration of bot to reach 30 RPM in one second
V = u + a * t
For robot starting from rest, u = 0;
a = V/t
= 3.14 * 0.05 /1
= 0.15707 m/s^2

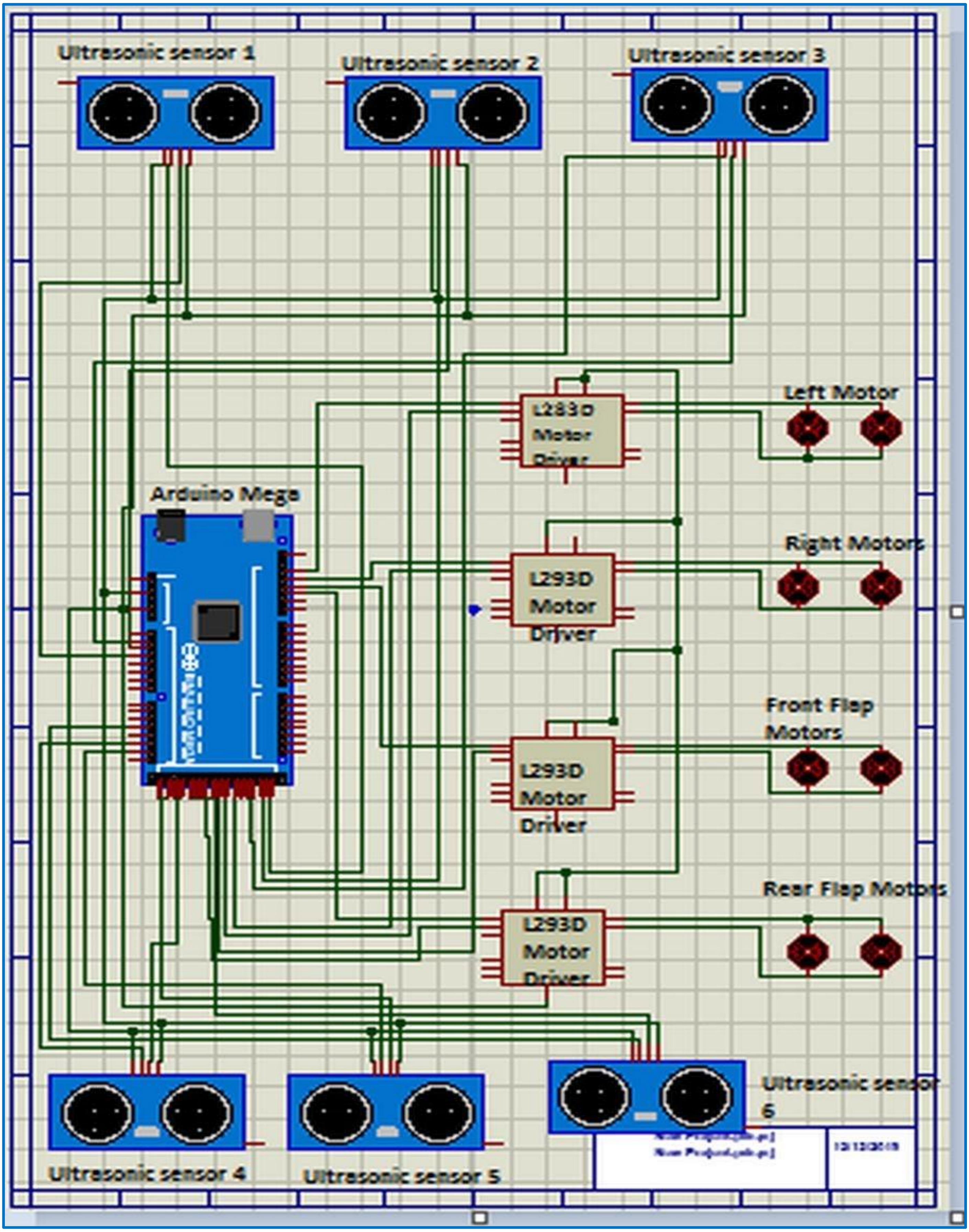
T = 1.5904 Kg-cm {assuming 100% efficiency}
T = 1.5904 *(100/58) Kg-cm
= **2.687 Kg-cm** {for 58% efficiency}

Selected Motor Specification:
Rated torque = 30 kg-cm
Motor Speed = 30 RPM

Lifting motors	
Torque	40 kg-cm
RPM	10
Locomotion motors	
Torque	30 kg-cm
RPM	30

ELECTRONICS

#CIRCUIT DIAGRAM



#COMPONENTS

S. No.	Component	**Specification**	Qt.	**Image**
1.	Ultrasonic sensor	HC-SR04 5V, 40KHz	**6**	
2.	Motor driver	Driver Model - RKI-1341 Operating voltage - 6 to18 V Max. current output - 20A No. of channels - 2 Continuous Current - 0 to 20A	**4**	
3.	Motors for Rack and Pinion Mechanism	Model number - RKI-1149 Operation Voltage - 12V Motor speed - 10 RPM Motor type - High torque geared motor Stall torque - 120Kgcm Rated torque - 40Kgcm	**4**	
4.	Motors	Model number - RKI-1146 Operation Voltage - 12V Motor speed - 30 RPM Motor type - High torque geared motor Stall torque - 68.18 Kgcm Rated torque - 30 Kgcm	**4**	
5.	Arduino Mega	Microcontroller - **Atmega2560** Operating Voltage - 5V Current Rating for I/O pin- 20mA Digital I/O pins - 54(of which 15 are PWM)	**1**	
6.	Battery	Model number - RKI 4403 **LI-ION 11.1V 7500mAH (2C)** 9X Li-ion 3.7V 2500mAh cells (3S3P) Discharge current - up to 15A	**1**	

CONTROL LOGIC

Process 1: The bot will start moving horizontally in forward direction on the ladder until the reading of front ultrasonic sensor becomes 15cm. Meanwhile, it will align itself using two side sensors and side wall.

Process 2: The bot will again start moving horizontally backward until the reading of backward ultrasonic sensor becomes 15cm. Meanwhile, it will again align itself using two side sensors and side wall.

Process 3: The bot will place itself one step-down in three parts:

a) The back slider will start moving downward until the sensor attached beneath the front slider reads value equal to ground clearance.

b) Now after moving 2-3 cm the middle body of the bot will start moving downward until the sensor attached beneath the middle body reads value equal to ground clearance.

c) Again after moving 2-3 cm the back slider of the bot will start moving downward until the sensor attached beneath the back slider reads value equal to ground clearance. And finally the whole bot will place itself to one step lower.

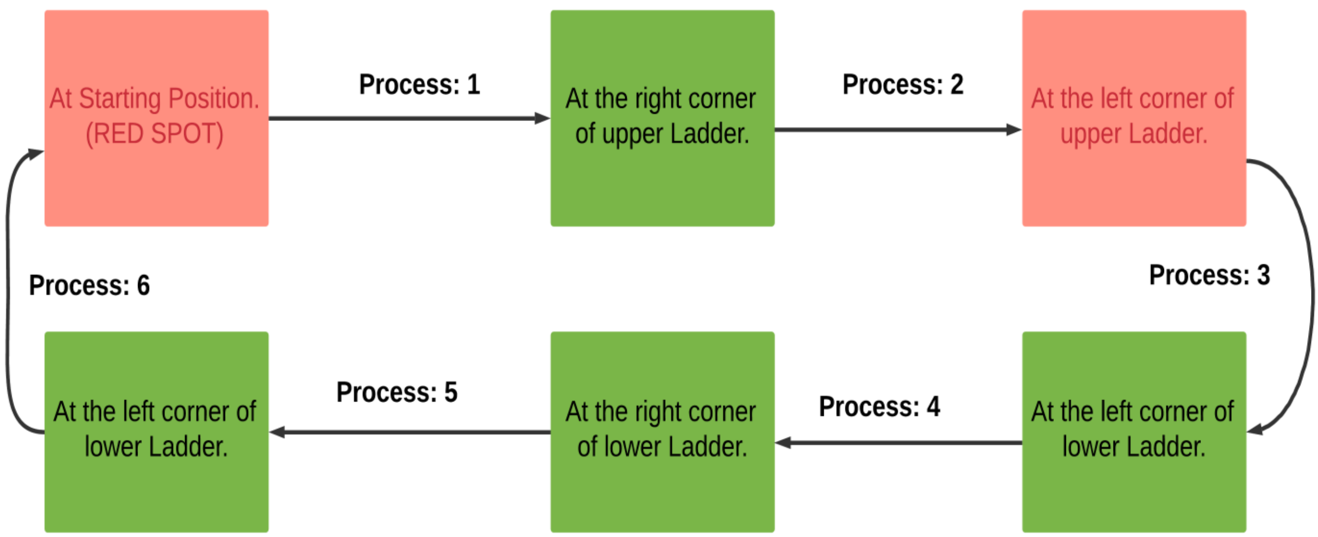
Process 3: Again the bot will move horizontally forward on the ladder until the front sensor ask itself to stop by detecting corner.

Process 4: Reverse of Process three in backward direction but upon the different lane.

Process 5: Reverse of Process two for moving itself to one step up.

Currently we have implemented sowing and ploughing which can be done parallel together in Process 3 and 4.

For Sowing: A slit like structure has been provided with the dispenser which limits



COST ESTIMATION

#COST OF THE PROTOTYPE

This cost was calculated by adding the total cost of components used to make the prototype.

Part	Cost
Chassis	Rs. 1400/-
Rack	Rs. 1400/-
Pinion	Rs. 500/-
Slider	Rs. 700/-
Sensors	Rs. 3000/-
Controller	Rs. 2000/-
Wheels/Locomotion system	Rs. 1000/-
Acrylic	Rs. 1000/-
Motors	Rs. 4000/-
Battery	Rs. 1700/-
Total cost	Rs. 16,700

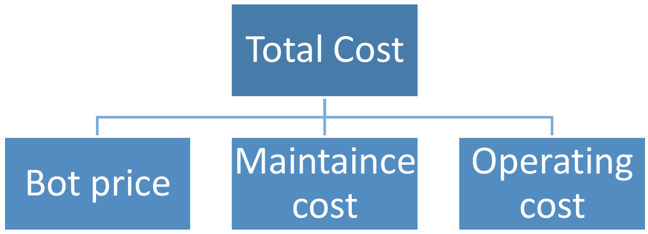
#COST OF SCALED MODEL

- The scaled model will be made my mass-manufacturing of components like chassis, rack and pinion.
- Also the battery needs to be upgraded. We will be using 200Ahr battery.

Part	Cost
Chassis	Rs. 800/-
Rack	Rs. 500/-
Pinion	Rs. 300/-
Slider	Rs. 500/-
Sensors	Rs. 2500/-
Controller	Rs. 1500/-
Wheels/Locomotion system	Rs. 800/-
Acrylic	Rs. 800/-
Motors	Rs. 3500/-
Battery	Rs. 13000/-
Total cost	Rs. 24,300

BUSINESS ANALYSIS

- The product has to sustain in market and for that it has to be profitable than other state-of art techniques.
- Apart from the fixed cost of bot, there is maintenance cost and operating cost which will increase linearly with farm size.
- Thus we need to find a point (in terms of farm size) where the bot will become profitable for the farmer instead of using labour.



#MAINTENANCE COST

Component	Maintenance	Cost
Chassis	Requires a few weld in a year. Considering one weld for on hectare	Rs. 10/-
Flaps	Only accidental damage. Once in 10 Hectares	Rs. 25/-
Rack	-	-
Pinion	-	-
Slider	Oiling required after 1 hectare	Rs. 15/-
Motors	Considering failure after operating in 10 Hectare	Rs. 400/-
Sensors	-	-
Controller	-	-
Mountings	Once in 10 hectare	Rs. 20/-
Total		Rs. 470/-

#OPERATING COST

Following calculations show the total consumption for one hectare in one operation for covering the area-

Area to capture:

Considering average width of one step: 3 m

The bot will cover each step in three rounds covering 1 m in each round

Average length of one step: 70 m

Total area of one step: 210 m^2

No of steps in one hectare: (10,000/210) = 48 steps

The bot will climb 25 steps come down 25 and then again repeat the same for next 25 steps [considering a hill of around 25 steps]

Total trips = 100 [50 upstairs and 50 downstairs]

Distance travelled

= Length of each step x no of rounds x no of steps

= 70 x 3 x 50

= 10,500 m

Horizontal travel time:

Speed of bot = RPM x π x Diameter of wheel

= 150 x π x 0.20

= 90 m/min

Total time = 10,500/90

= 116 min

= 2 hours

Considering 90% efficiency = 2.2 hours

Lifting Time:

Time per lift = 1 min

Total lifts = 100

Total time = 100 min

Considering 75% efficiency = 150 min = 2.5 hours

Energy consumption:

Driving motors consume 0.5 Amp/s

Total consumption = 2.2 x 3600 x 0.5 = 3,960 Amp

Lifting motors consume 1 Amp/s

Total consumption = 2.5 x 1 x 3600 = 9,000 Amp

Total = 12,960 Amp ≈ 13,000 Amp of 12 Volt supply

With a 200 AH battery it requires 60 charges

Each charge consumes 1Kwhr (battery rating)

Total consumption = 60 units

= 60 x cost of one unit

= 60 x 6

= Rs. 360/-

#COMPARISON WITH LABOR COST

Total cost for one hectare for one run

= Operating cost + Maintenance cost

= **Rs. 830/-**

For sowing, irrigation and ploughing of a crop (say saffron) = 90 days

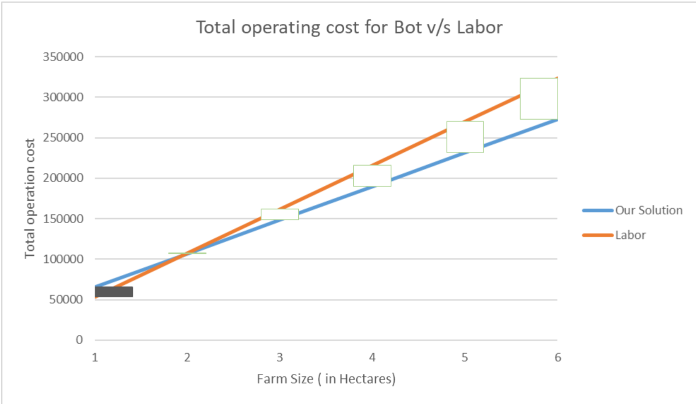
Labor cost for one hectare = 300 x 90 x 2

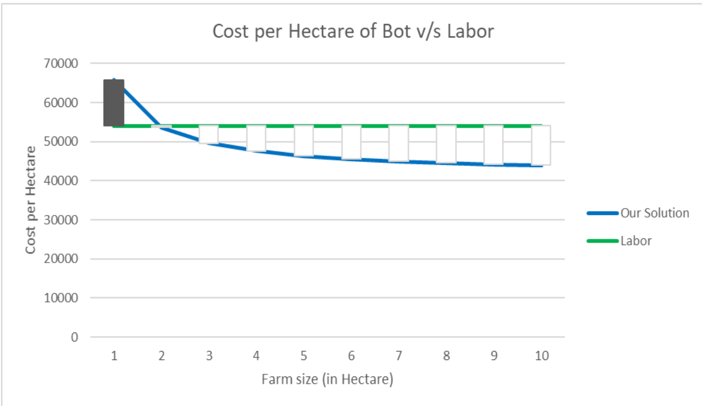
= Rs. 54,000/- [considering two labor in one hectare]

Operating cost of our bot for on hectare = 830 x 50

= Rs. 41,500/-

#BREAK EVEN POINT





This tells us that for farm size greater than 2 hectares our solution is a profitable option.

And as per a 2018 survey 15% of Indian farmers have land holding greater than 2 hectares.

Also, in areas where terrace farming is used there are more of bigger plantations thus we can assume that 25% of those farmers have bigger than 2 hectares of farm.

Thus we can acquire around 25% of the terrace farming market.

FURTHER IMPROVEMENTS

• Suspension system can be added for the smooth movement of the robot in rough terrain, also helps in lifting up/down processes.

• Implementation of image processing, along with LIDAR, almost exact position and type of weeds, animals, persons etc. can be detected and according to the situation, the particular process will be initiated. Like when it's weed, weed remover process will be activated and for stray animals some alarm will be activated.

• ModulariZation of multiple parts can enhance the feasibility and increase the target areas where the bot can be deployed. We already have facilities for ploughing and sowing. We can include parts for

i) Watering
ii) Weedicide/pesticide sprinkling
iii) Harvesting

• By installing some sensors on the bot, during any kind of process like ploughing or sowing the properties like humidity, particle size, type of soils and many others can be recorded and using wi-fi modules all the data can be stored on cloud based services from which the relevant authority can access and generate soil health card and respond accordingly for the betterment of the soil health for a particular type of crop.

• Battery Management System: There will be a system devoted to calculations of power consumptions. Whenever battery is discharged down to 20%, it will send message to the owner, so that he can recharge it. At the same time some alarm can also be beeped indicating battery is discharged down to a particular level.

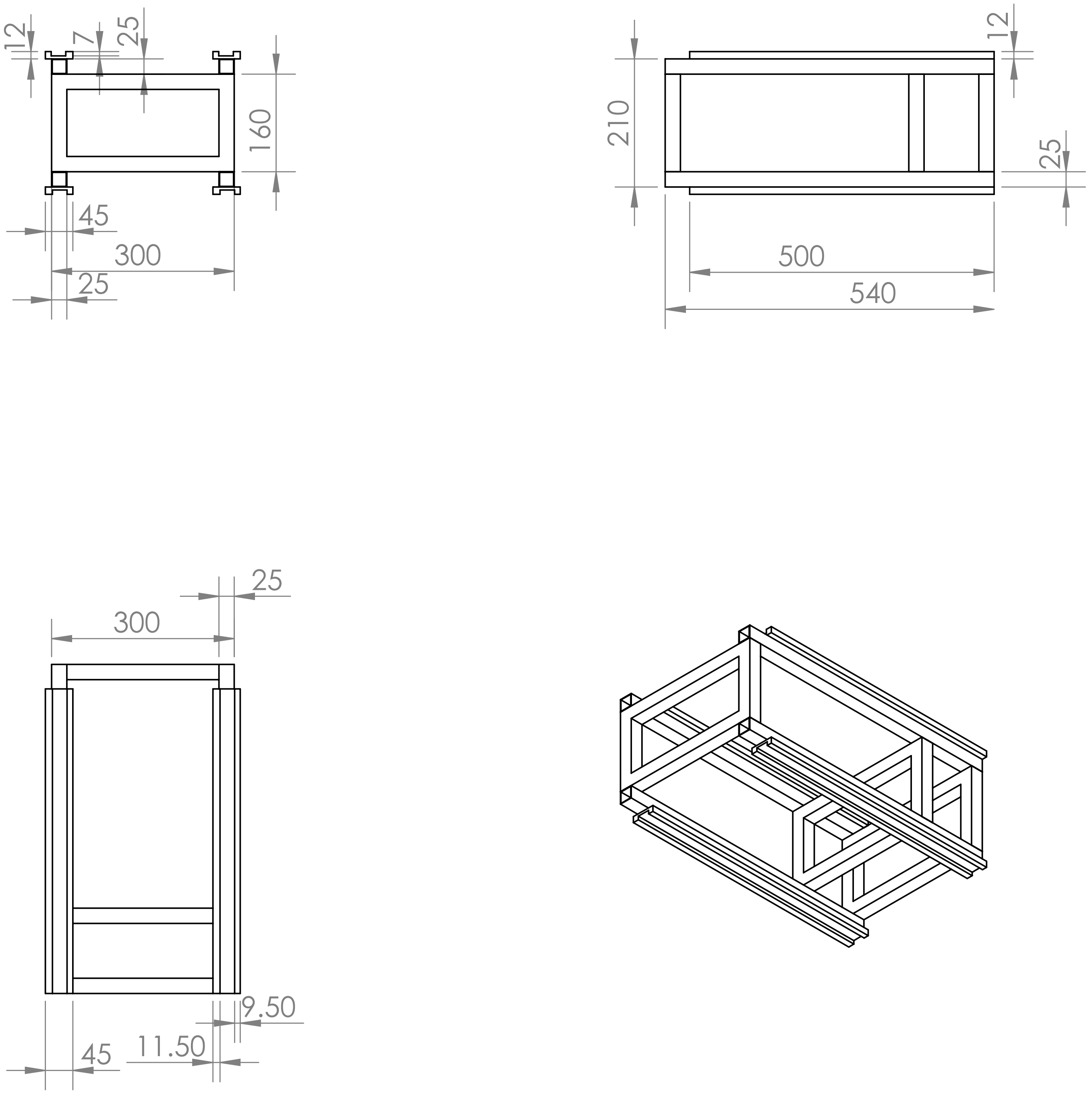
PSEUDO CODE

Pseudo code for horizontal movement with alignment.

```
void loop(){
        forward();
        while( abs(ultra_sonic_left_front - ultra_sonic_left_back) > tolerable_error ){
                stop_all_motors();
                int time = abs(ultra_sonic_left_front - ultra_sonic_left_back)*100;
                if((ultra_sonic_left_front - ultra_sonic_left_back) > tolerable_error)
                        turn_left(time);
                else
                        turn_right(time);
        }
        if( has_reached_corner_point() ){
                stop
                shift_right(); // for changing the lane of the bot
                reverse_direction();
        }
}
```

Pseudo code for upward downward.

```
upward(){
        // State 1: All parts(front slider, back slider and main body) of the bot is at the lower position.
        while(ultra_sonic_front_wing_bottom<40) {
                upward_front_wing();
        }
        stop_all_motors();
        forward(time); // small time.
        // State 2: Front wing is at the upper ladder and rest part is on the lower position.
        while(ultra_sonic_chassis_bottom<40){
                downward_front_wing();
                downward_back_wing();
        }
        stop_all_motors();
        forward(time); // small time.
        // State 3: Front wing and main body is at upper position but back wing is at lower position.
        while(ultra_sonic_back_wing_bottom<40){
                upward_back_wing();
        }
        stop_all_motors();
        forward(time); // small time.
        // State 4: All parts(front slider, back slider and main body) of the bot is at the lower position.
}
```



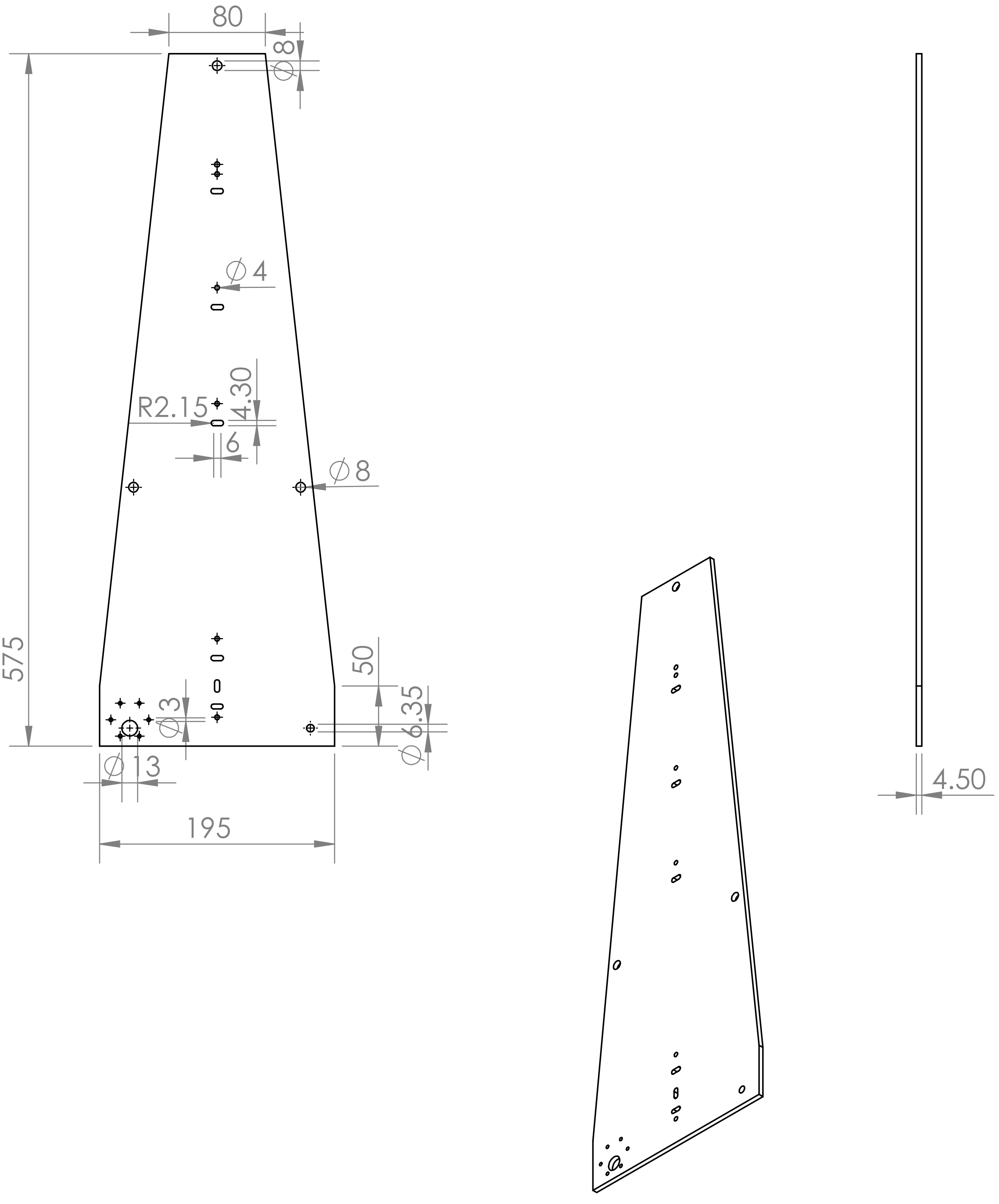
All dimensions are in mm.

TITLE: DIC's Terrace Farming, Inter IIT Tech Meet - IIT PATNA

DWG NO. Main Frame

A4

SCALE:1:10



All dimensions are in mm.

TITLE:

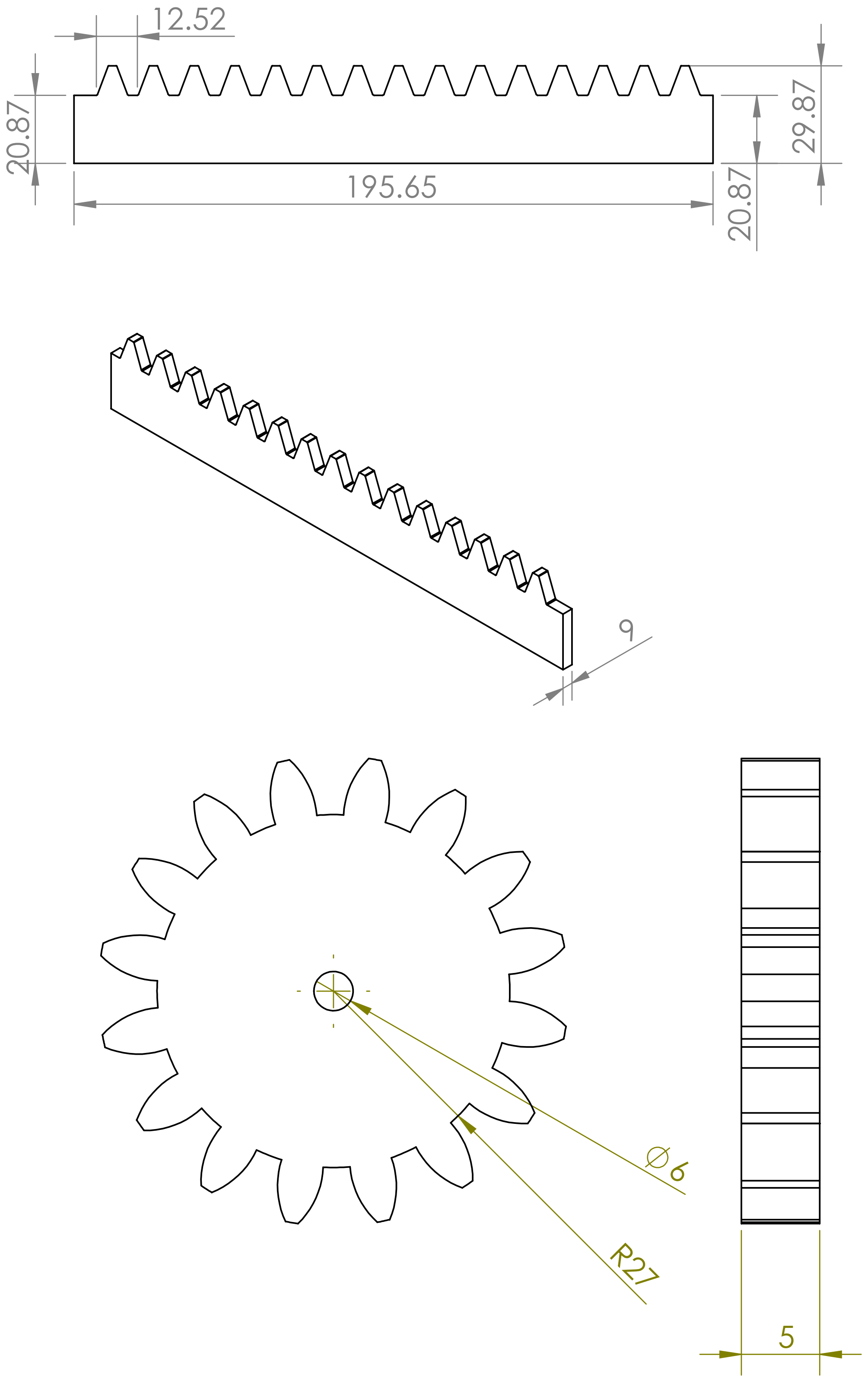
DIC's Terrace Farming,
Inter IIT Tech Meet - IIT PATNA

DWG NO.

Wings

A4

SCALE:1:5

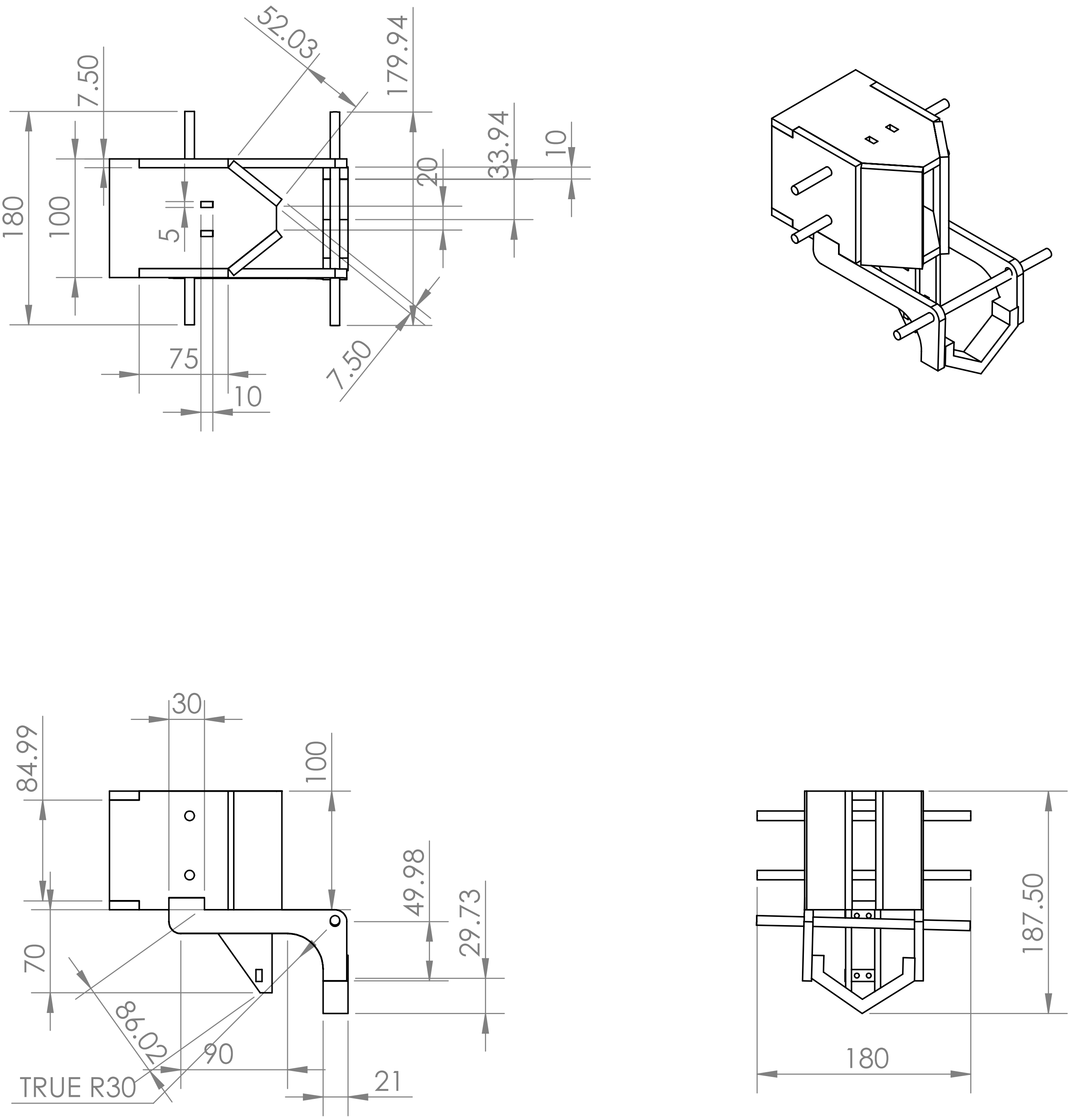


All dimensions are in mm.

TITLE: DIC's Terrace Farming, Inter IIT Tech Meet - IIT PATNA

DWG NO. RACK AND PINION	A4

SCALE:1:2



All dimensions are in mm.

TITLE: DIC's TERRACE FARMING, INTER IIT TECH MEET: IIT PATNA

DWG NO. Seed dispenser

A4

SCALE:1:5