TEAM 4

HARDWARE MODELLING REPORT

Contents

Introduction

Human species have dominated the planet earth because of one crucial attribute that distinguishes us from other living forms is to build tools to overcome and extend our biological limitations. This quest has led to the invention of wheel, controlling of fire and many more history defining moments. Fast forwarding to time of industrial age automation has been the key concept behind developing tools that reduces human intervention. Automation dates back as early as 1450's with the invention of printing press which lays the foundation behind synergy of human minds to grow exponentially.

Automation in industries are mostly programmed to carry out certain work. But the exponentially growing semiconductor industry has led to development of economically viable sensors with pinpoint accuracy combined with the internet gives a whole new dimension to the world of automation. The direct consequence being machines getting intelligent and very versatile. Our work here is an attempt to extend this automation quest. India's major economic dependency on agriculture, the issue of global climate change and energy dependency has been the major motivation in designing the product.

Product: GREENDROID (Solar powered Multipurpose autonomous droid)

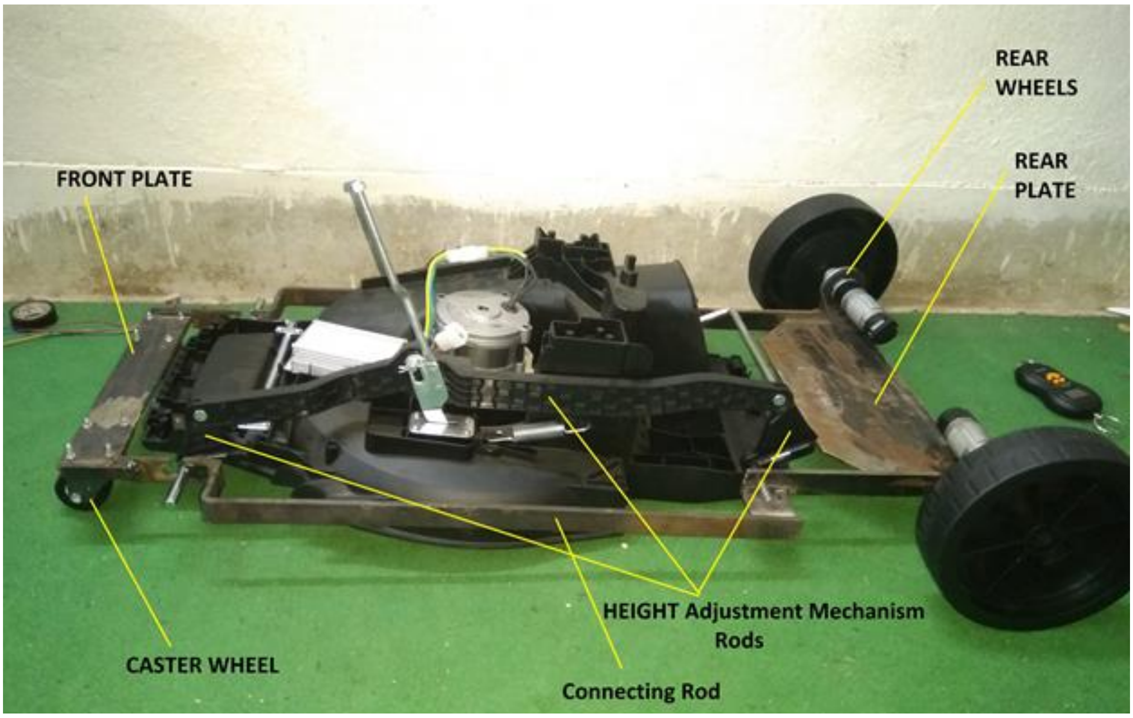
It has one basic function and different modules designed for different tasks. In the demonstration bot we have one basic function of autonomous lawn mowing with height adjustment and a seeding module. The robot takes instruction through a mobile application or onboard interface, instruction being the area mapped for mowing and seeding pattern on the field. The robot performs the instructed operation autonomously with the help of GPS based localization and mapping and sonar sensors based obstacle avoidance techniques. The robot is solar powered which makes the product usable in remote locations deprived of power supply.

Uses:

- Lawn mowing, the product makes mowing happen in a click of a button making human intervention in mowing essentially nil. This finds implication at our very own campus, lots of workers are involved in seemingly this tedious work. The height adjustment function can be used to design the field at our will making it very suitable for international playgrounds, gardens etc.
- Seeding module, the product makes it easier for farmers to plough and seed with a click of a button adding its energy independency makes it a brilliant step in use of modern technology in agriculture sector.
- Security module, this makes robot as a mobile robot powered with vision and sensors to detect any suspected act or emergency situation which it reports back to the owner. Combined functionality of autonomous lawn mowing and security module makes it a brilliant technological assistance in home maintenance and security.

The product, autonomous, easy and reliable seems to cover various sectors of work. It is well suited with the technological paradigm we are moving into thus making it easier to penetrate the market.

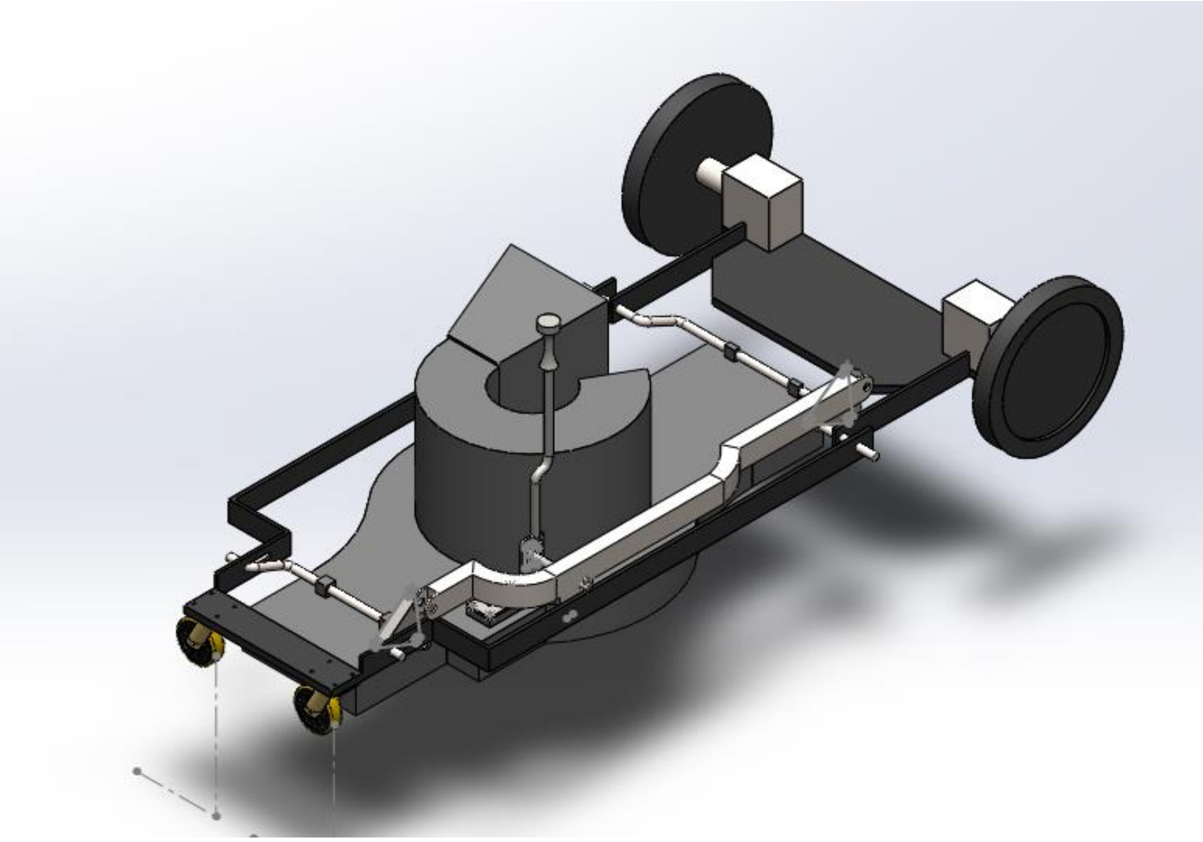
Mechanical Design



Mechanical Subsystem

Chassis

The chassis is designed to support the grass mowing basic module and additional modules such as seed sowing and ploughing. The chassis is equipped with a four bar linkage mechanism to provide variable height to the blade so as to control the height of the grass trimmed. The front plate is supported by Caster wheels and the driving motors are mounted on the rear plate.



Finite Element Analysis of Chassis

Designing of the chassis involved the following steps

1. Defining the mounting points of wheels which will provide the normal force
2. Defining the mounting points of blade cover (which is considered as dead weight)
3. Deciding the chassis thickness according to the stress on the chassis components

AISI 1020 Low Carbon/Low Tensile Steel was used as material for all further analysis due to its superior properties and easy availability. Our aim was to get a factor of safety of at least 10. Loads were applied on the chassis as given in the following figure:

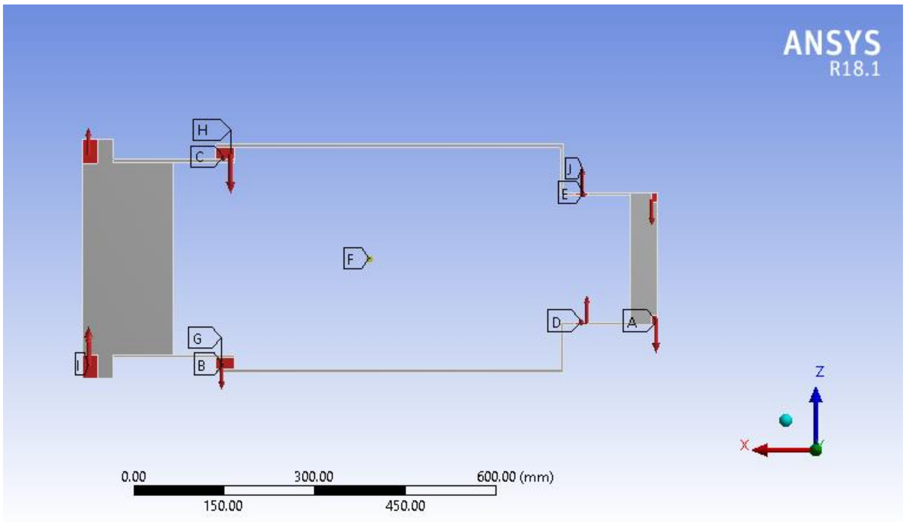


Figure. Loads applied on the chassis

We iterated the same loads on different chassis thickness to get a factor of safety just equal to 10. After this, we selected the standard plate thickness which was just more than the calculated chassis thickness and which was available in the market. As a result, plate thickness of 5mm made of material AISI 1020 Low Carbon/Low Tensile Steel was used to manufacture the chassis. Final factor of safety which the chassis provides is 15. Following figure show the analysis results which were performed on Ansys R18.1 (Student Version) static structural module.

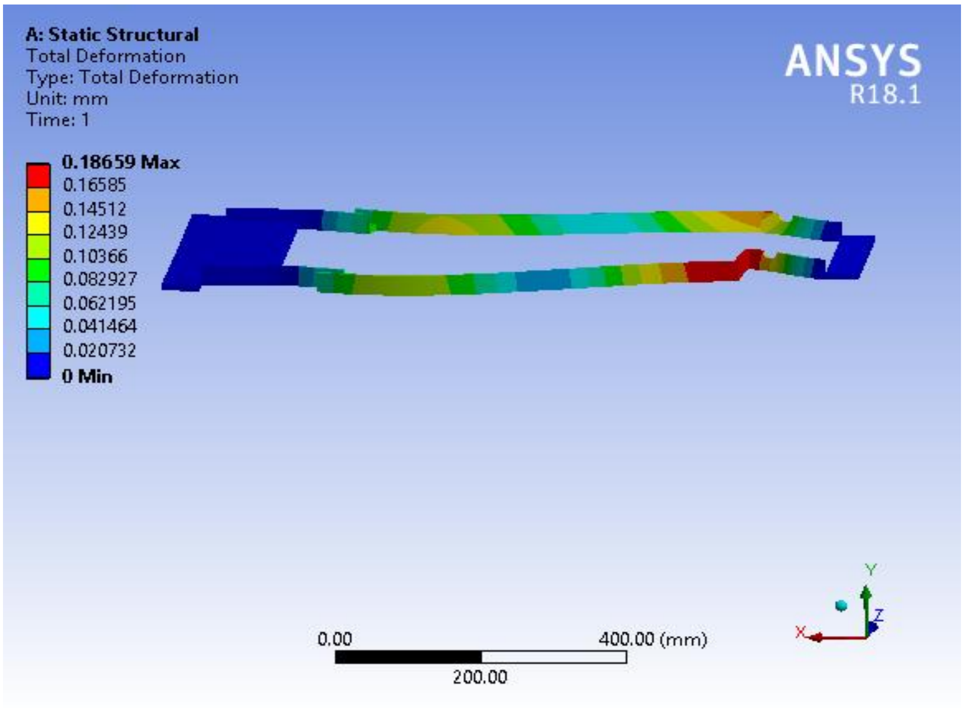


Figure. Total deformation in chassis (Deformation max = 0.18659mm)

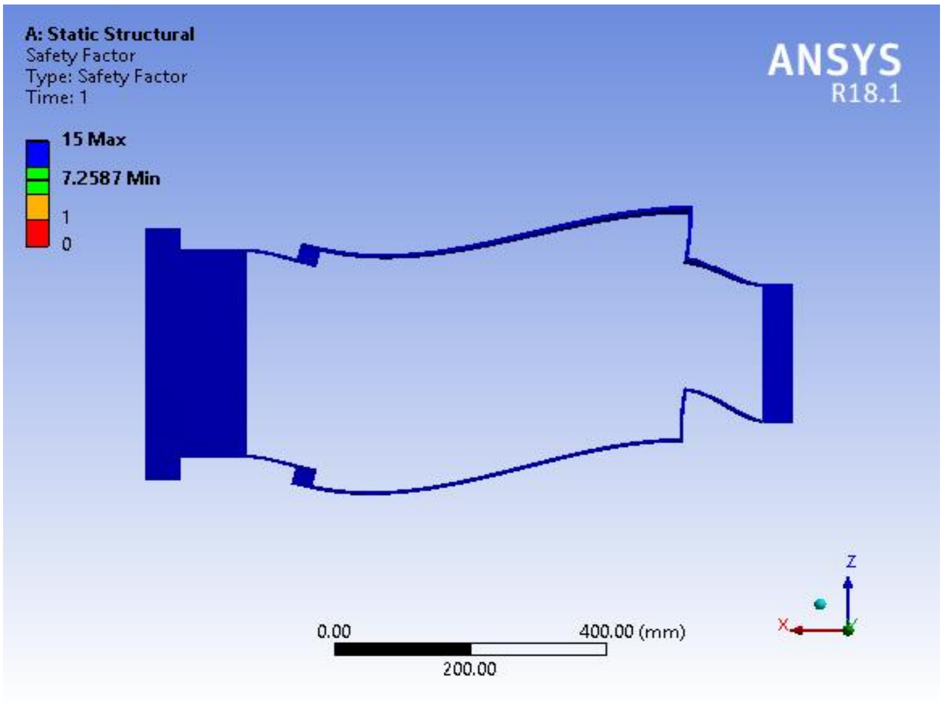


Figure. Factor of Safety (FOS min = 7.2587)

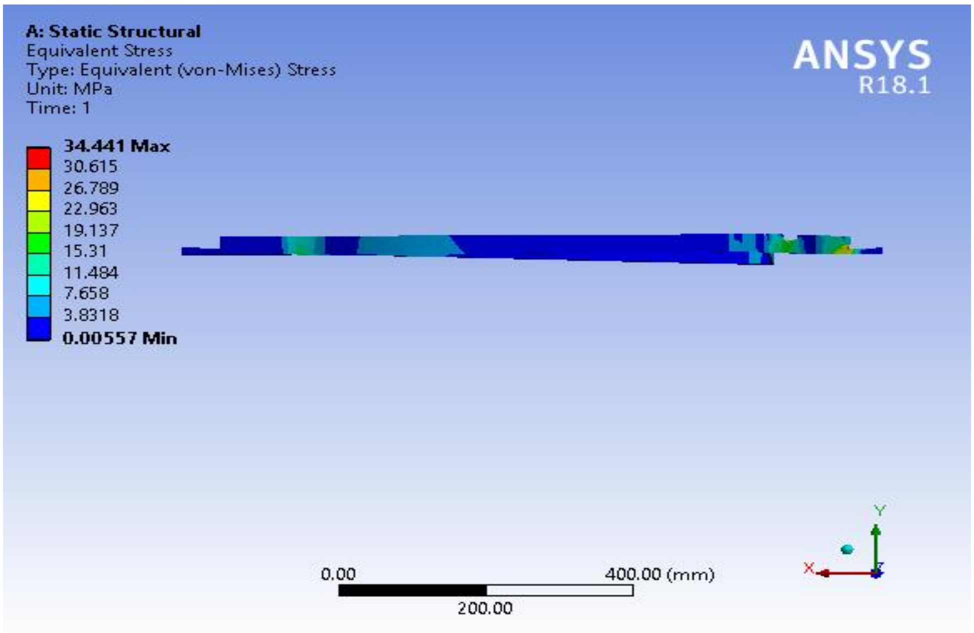
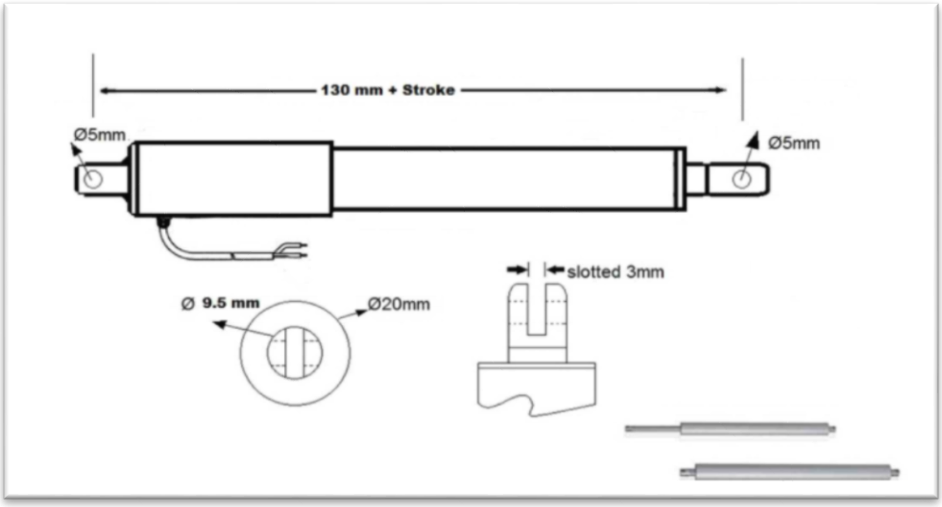


Figure. Equivalent von-Mises stress (max = 34.4MPa) – Side View

Height Adjustability

The design of the robot provides height adjustability. The design is such that the robot can cut grass at different levels of height according to requirement. This feature also helps in the

ploughing and seeding process. The height adjustment is actuated through the lever using a linear actuator mounted on the blade cover. The mechanism used here is the simple 4-bar mechanism. It can be used to cut grass in different areas which are overgrown with grass. Thus it provides a large cutting height range from 3 cm to 7 cm.
The specifications of the actuator are given below:



Voltage	No Load Speed	Max Load Speed	Stroke	Max Load	Limit Switch
12VDC	2 mm/sec	0.5 amp	150 mm	50N	Built in

Modules

Seeding

In order to eliminate the intensive human labor involved in seeding process in farms, the robot provides a complete solution to seeding in farms. The robot can be fed with farm map and it will determine the optimum seeding lines to sow seeds at consistent distance in the area. It has a furrow opening attachment, a seed dispenser mechanism and a seed covering attachment. The engagement of furrow with soil is done using the height adjusting mechanism. A servo motor combined with a pocketed turbine is used to dispense seeds to the soil at the required distance.

Lawn Mowing

The robot is capable of cutting overgrown grass autonomously at required length. It houses a sharp blade at the center along with a plastic blade cover which discards the grass to the rear of the robot after cutting. The cutting blade is powered by a high powered motor which is mounted on the top of blade cover. The height of the blade can be adjusted using the four bar linkage mechanism which connects the blade cover to the chassis.

Material Considerations

Blade Cover

Material: 210 dener polyester
Properties:

- Light Weight
- High Strength
- Good durability and breathable properties
- Doesn't stretch or Shrink
- Water and mildew resistant

Chassis

Material: AISI 1020 Low Carbon/Low Tensile Steel
Properties:

- High Hardness
- High Machinability
- High Weldability
- High density, hence heavy thus providing weight balance and stability to the bot

Mower blades

Material: High-Carbon, Nickel-alloy steel
Properties:

- Extremely hard
- Resistant to wear and breakage
- Heat Treated
- Gives consistent hardness throughout the blade
- Helps to keep blade straight, even in tough use conditions, for level mowing
- Reduces wear and breakage for longer blade life

Drive Mechanism

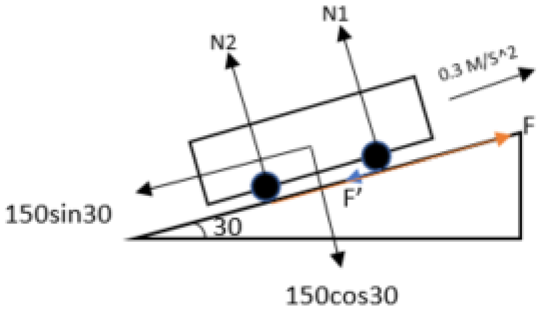
Drive mechanism was designed keeping in mind the following objectives:

- Implementation of differential drive to allow the robot to turn in the desired direction
- Capability to take zero radius turns to simplify path planning
- Independent driving motors to avoid mechanical complexity in differential drive

The differential drive consists of the following components

Driving motors

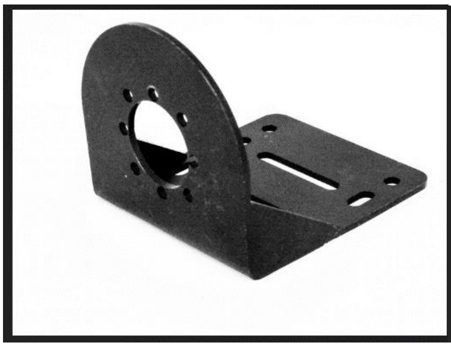
Two driving motors were used to drive the rear wheels. Rear wheel drive ensured a balanced weight distribution of the robot. Rear wheel drive also ensures that there is enough traction on the drive wheels when the robot accelerated from rest. When the robot will accelerate, the weight of the robot will be transferred to the rear of the robot and increase normal force on the rear wheels. Higher normal force will ensure higher traction on the rear wheels which will avoid the slipping of the drive wheels.

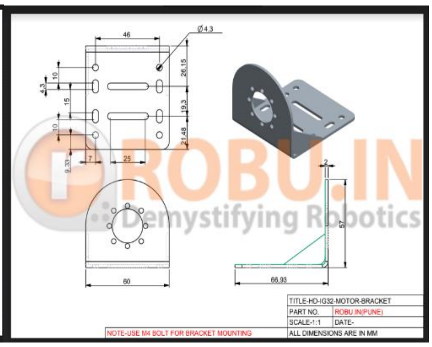


$$F - F' - 150\sin30 = 150*0.3$$
$$F' = 0.4*150\cos30*0.4 = 20.1\ N$$
$$F = 140.1$$
$$\tau = F*r = 140.1*0.1 = 14.01\ Nm$$
$$\text{Torque in individual wheel} = \tau / 2 = 7.005\ Nm$$

Motor clamps

Motor clamps are used to clamp the motor to the chassis using bolts.



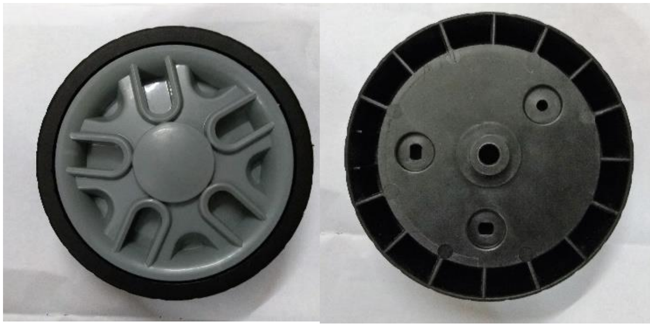


Shaft coupler

Shaft coupler connects the wheel shaft and the motor output shaft which are of different diameters

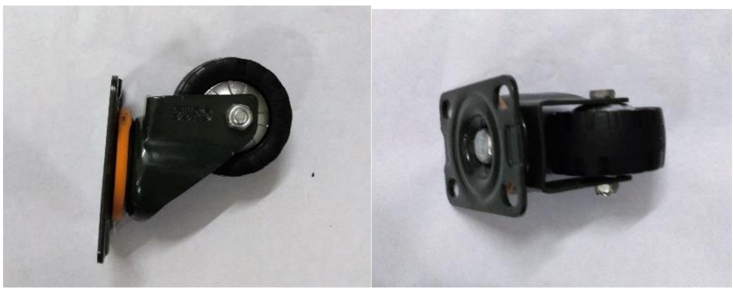
Rear Wheels

Wheels of large diameter were selected as the rear wheels because of high torque and low rpm requirement of the robot. The wheels are rotated at different angular speeds by the driving motor to turn the robot in the desired direction.



Front wheels

Swivel Caster wheels were used as the front wheels because it can rotate and roll in order to allow movement in any direction. This allows the rear wheels to take a zero radius turn by rotating them in opposite directions because the caster wheels follow the direction in which rear drive wheels pull them.



Cutting Mechanism

The grass cutting mechanism consist of three main components:

Blade

Blade is made of High-Carbon, Nickel-alloy steel and is mounted to the blade cover at the bottom of the robot. The blade has sharp edges and rotates with high angular velocity. Grass which is longer than the distance of blade from the ground gets cut due to shear when it comes in contact with the blade

Blade cover

Blade cover confines the cut grass under the robot and provides it an escape path to remove the cut grass from the rear of the robot. The blade cover mounts the high power motor which powers the cutting blade. The blade cover is mounted to the chassis using a 4-bar height adjustment mechanism and a tension spring.

Cutting Motor

The cutting motor is used to power the cutting blade to cut the grass. A picture of the cutting blade is given below:

Seeding Mechanism

Seed reservoir

Seed reservoir is made up of a transparent material, polyethylene terephthalate which has a converging bottom. The reservoir holds the seeds and directs them towards the slotted rotor. The diameter of the bottom of the reservoir is such that only a single seed can pass at a time.

Slotted rotor

A wooden rotor is attached to the servo motor and contains slots to hold seeds. The slots are sized such that they can only contain a single seed. Seeds are dispensed from the lowest slot containing the seed due to gravity. There are 4 slots on the rotor separated by 90-degree angle. So, 4 seeds are dispensed for every rotation of the rotor.

Servo motor

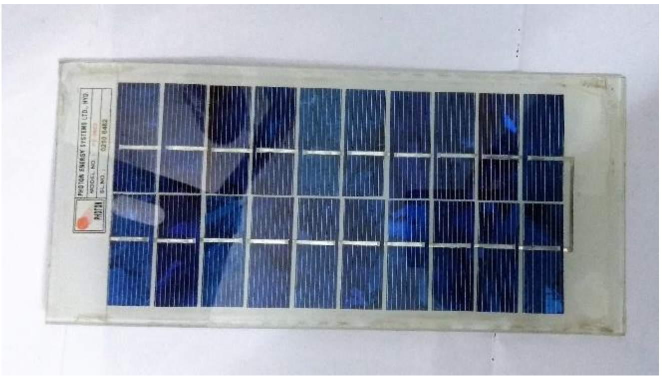
The servo motor is responsible for timely delivery of the seeds. It rotates the rotor by 90 degrees to dispense one seed. The rotation timings of servo motor are synchronized with the speed of the robot which ensures that seeds are dispensed at consistent distances.

Mechanism container

A perspex container which is mounted on the chassis makes sure that seeds are confined to the required path and they do not escape out of the mechanism near the rotor. It also mounts the servo motor.

Solar Panels

The solar panels used is rated at 3W and 9VDC per module. The material used in the solar cell is monocrystalline silicate which provides higher efficiency than amorphous silicate. Several modules are used to charge the battery which drives the robot.



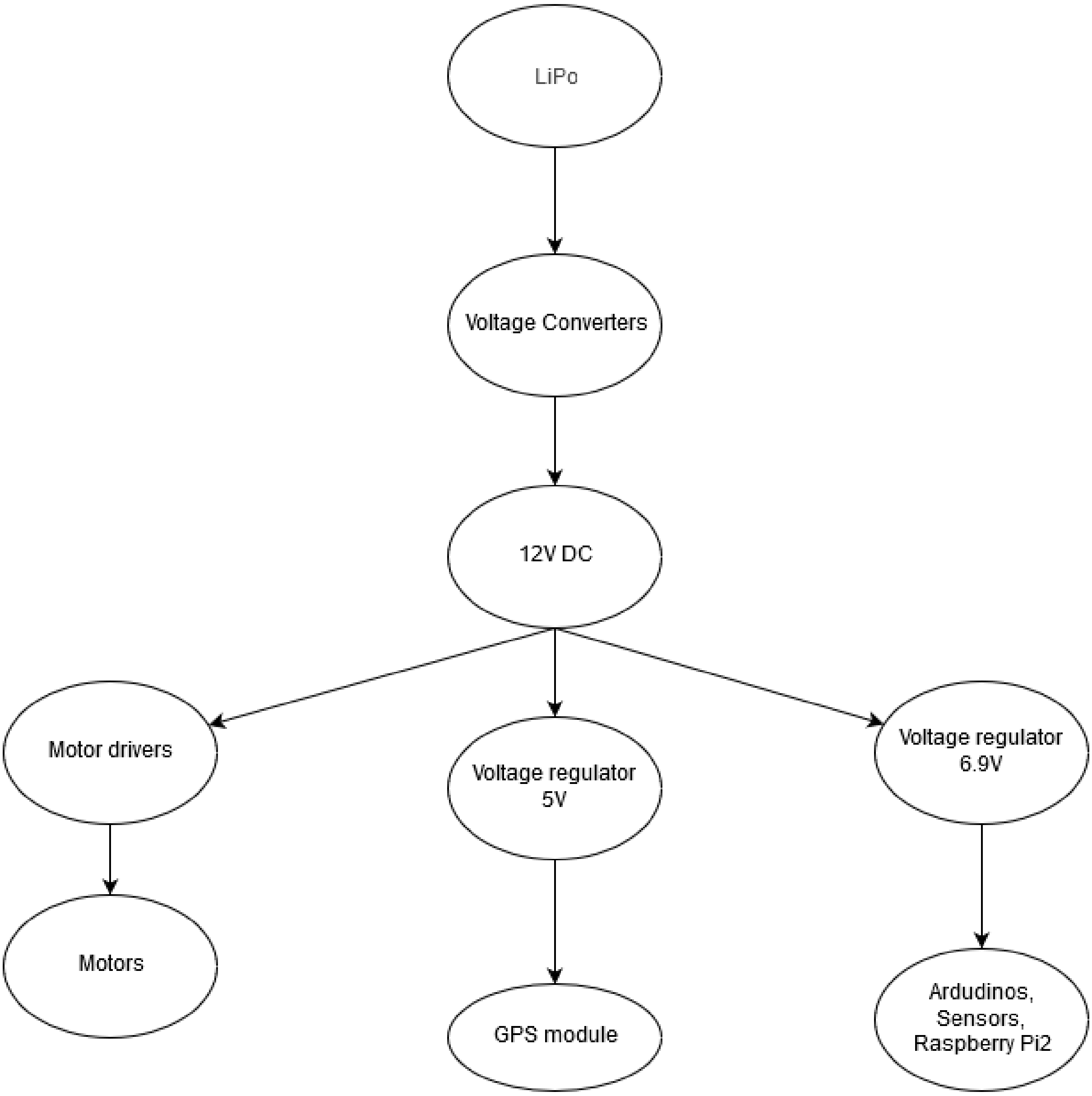
Motor Selection

Actuation is needed to execute the drive motion, the cutting motion, the active height control and the active seed sowing motion. Taking into consideration the speed constraints, maneuverability constraints, loading constraints and other dynamical constraints, the power, torque and speed requirements were derived. The electrical power requirements depend on the choice of the actuators, hence the actuators were chosen to economize the expense on power components and actuators, but satisfied the power, torque and speed requirements.

Electronic Architecture

Power Subsystem

The robot is primarily powered by 2 LiPo batteries. As different systems require different voltage and currents, voltage converter ICs and buck-boost converters have been used in the circuits. As the high torque servos and DC motor have been connected on different batteries to avoid any damage due to high current extraction. As the motors can still extract high currents from the batteries, safety fuses have been used.

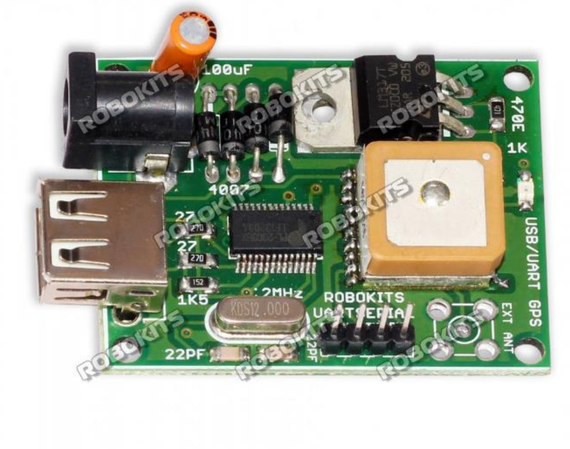


Sensing

The automation of the bot is implemented through positioning provided by the satellites i.e. GPS. To enhance the usual 10-meter accuracy provided by the GPS system IMU (Inertial Measurement Unit) is appropriated. The autonomous mowing and sowing operation is achieved by constantly tracking the robot's position with respect to the frame of reference fixed to the work field after it has been mapped. The sensors work in tandem to track the bot position as follows:

USB/UART GPS Module [RKI-1610]

After trilateration, the module provided with patch antenna on top outputs NMEA $GPGGA data stream which is parsed into Navigational Coordinates - Latitude and Longitude employed in robot's localization.

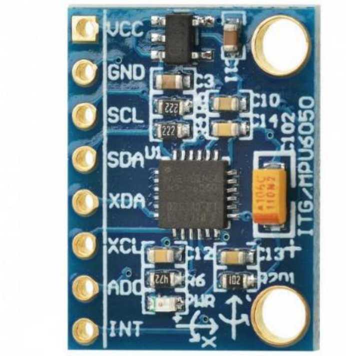


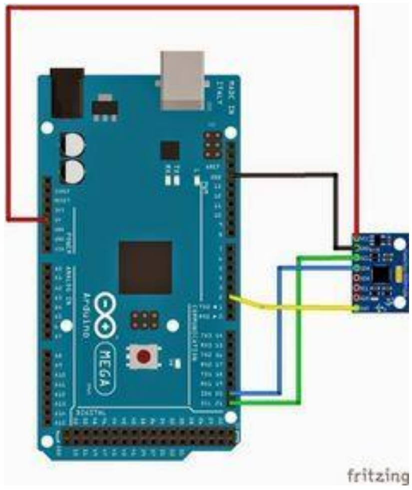
Specifications:

- Low Power Consumption : 55mA @ acquisition, 40mA @ tracking
- Position Accuracy Without aid: 3m 2D-RMS
- DGPS (RTM, SBAS (WAAS, EGNOS, MASA)):2.5m 2D-RMS
- Data output Baud rate : 9600 bps
- Max. Update Rate : 5Hz (Default: 1 Hz)

MPU6050: 6 Axis MEMS Accelerometer + MEMS Gyro meter - GY-521

The inertial data i.e. linear accelerations and the angular velocities along the axis obtained from the sensor is fed into an orientation filter to extract the data in Quaternion orientation form employed in active localization.





Specification:

- Accelerometer ranges: ±2, ±4, ±8, ±16g
- Gyroscope ranges: ± 250, 500, 1000, 2000 °/s
- Voltage range: 3.3V - 5V (the module include a low drop-out voltage regulator)

Interfacing

It comprises the methods by which all the sensors and actuators communicate with the central controller. Since the embedded architecture on GREENDROID is based on the distributed processing of the varied data, it is required to have a proper communication scheme at each level. The central controller we have used here is Raspberry Pi2. It communicates with the three Arduino MEGA boards and also receives the control commands for the actuators like motors and servos. On each Arduino an interfacing code is developed individually and uniquely.

We have two major types of interfaces in the GREENDROID.

Sensors-Arduino Interface: - I2C and Serial UART

The raw data received from the sensors is processed and packed at the Arduino board. The process of receiving the data from the sensors is done with the required communication protocol. Inertial Measurement Unit (IMU) sensor and GPS module are interfaced with the Arduino via the I2C and Serial UART Communication protocol respectively.

I2C is the two wire interface where one wire is for the Serial Data signal and other for the Serial Clock signal. Arduino Board as the master device shares its clock signal and a single data line is used for the transfer of data between master and the slave as per the request for data generated from the master.

Serial UART Communication with GPS is achieved through Receiver and Transmitter signal lines. The GPS module sends the NMEA data streams which are then parsed in Arduino into Latitude and Longitude.

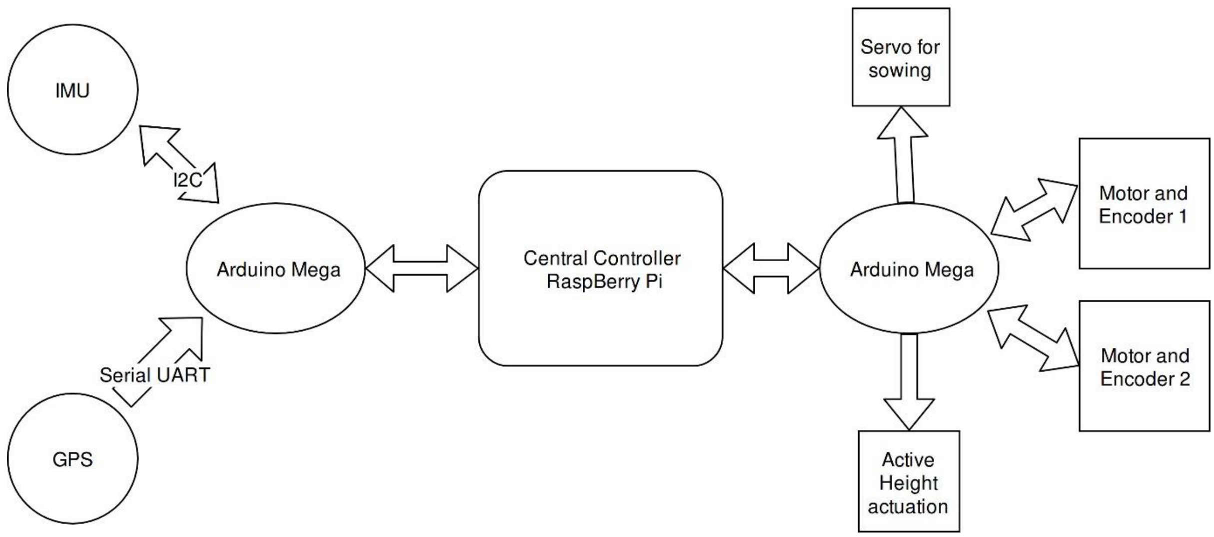
Arduino-Raspberry Pi 2 Interface: - Serial

The processed data at the Arduino boards is sent to the Raspberry Pi 2 for the localization with the use of serial communication. We have used Robot Operating System (ROS) to integrate all the inter communicating nodes at the one place. With the use of ROS serial library it has become a lot handier to communicate between Arduino and RPi.

Arduino Boards sends following data to the Raspberry Pi:

- Quaternions
- Angular Velocities
- Linear Acceleration
- Parsed GPS data
- Processed data of Encoders

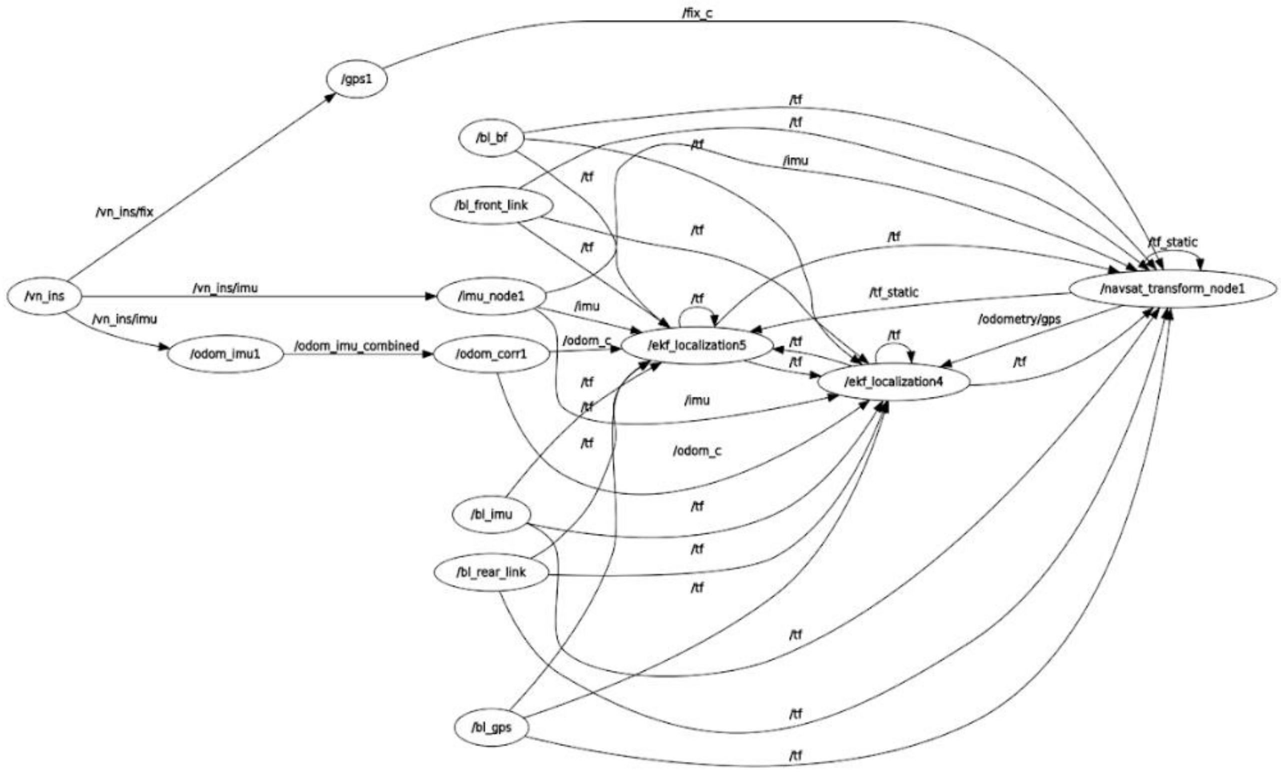
Simultaneously Raspberry Pi also sends the control commands to the Arduino which eventually actuates the motors and servos.



Software Architecture

Localization

The backbone of spatial awareness of a robot is localization. Proprioceptive sensors used are IMUs and Motor Encoders. Environmental sensor used is GPS. Data from proprioceptive and environmental sensor are fed into a Localization package. Localization package consist of extended Kalman filter (EKF) which is used to filter the sensory data and then get pose estimation from the filtered sensory data. Mapping is used to constantly update cut and uncut area. Mapping is done by using a flag which is toggled when robot visits corresponding grid. We are using ROS to integrate the system of Kalman filter and pose estimation. The following image explains the ROS architecture:

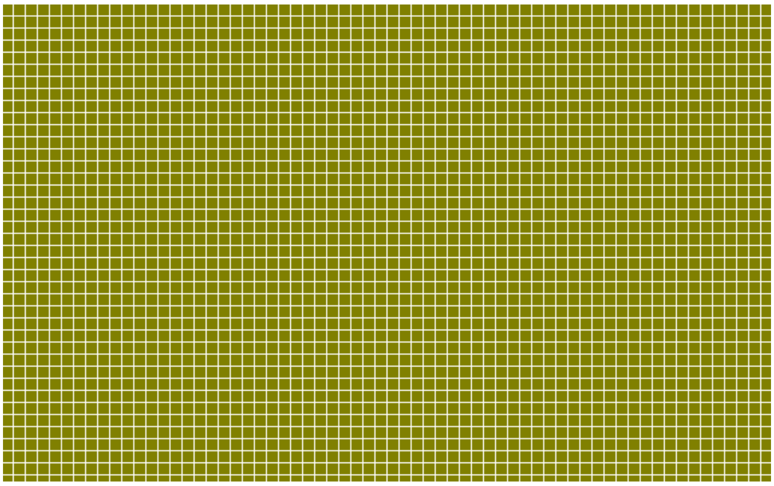


Waypoint Generation

Important for navigation of a robot is the generation of targets for the bots to traverse to. For the generation of such waypoints a Breadth First Search approach is adopted to mark the entire lawn, to generate a possible mowable area (this part of the algorithm ignores the presence of obstacles).

Then the entire area to be cut is divided into smaller grids such that when the mower navigates, then at each new location, it at least cuts the grass that is represented by one grid cell.

Again, these waypoints are marked for traversal in a Breadth - First Fashion and then these waypoints are passed to the waypoint navigator and successively to the path planning algorithm.



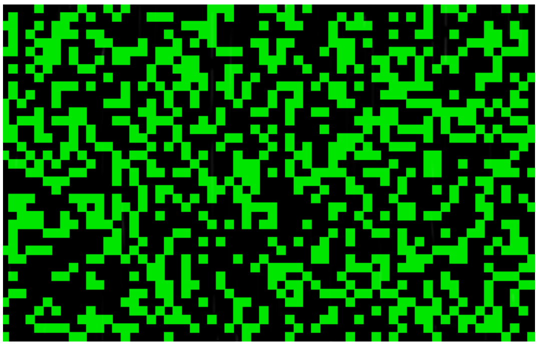
The above image shows the mowable area divided into the grid as described above

Waypoint Navigation

Through the waypoint generation algorithm, we successfully generate the set of possible waypoints. Now we have to choose a target from the large set of viable waypoints.

- For this we follow two complementary approaches one of which is a randomized algorithm to select a waypoint at random from the set of those waypoints whose distance from the current robot location is more than that of half the total number of waypoints. And then we mark the waypoints as traversed and remove them from the set of waypoints when the mower traverse over a particular grid cell.
- The second and the more conventional approach for lawn mowers is a more systematic selection of waypoints in which the bot follows a zigzag systematic path to mow the entire lawn.

These former approach is good for exploring the entire lawn initially as this method upon encountering obstacles can just discard a particular waypoint and select a new one. The latter method is employed after the completion of exploration to get a neat and fine cut.



An intermediate stage during the randomized waypoint selection. Here the green represents the cut cells and the black represents the uncut cells.

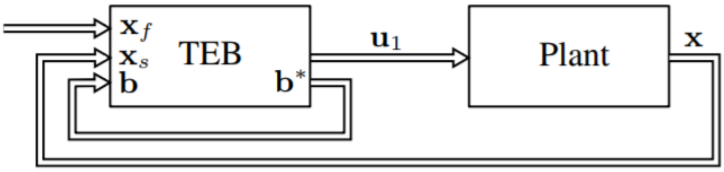
An intermediate stage during the sequential waypoint selection.

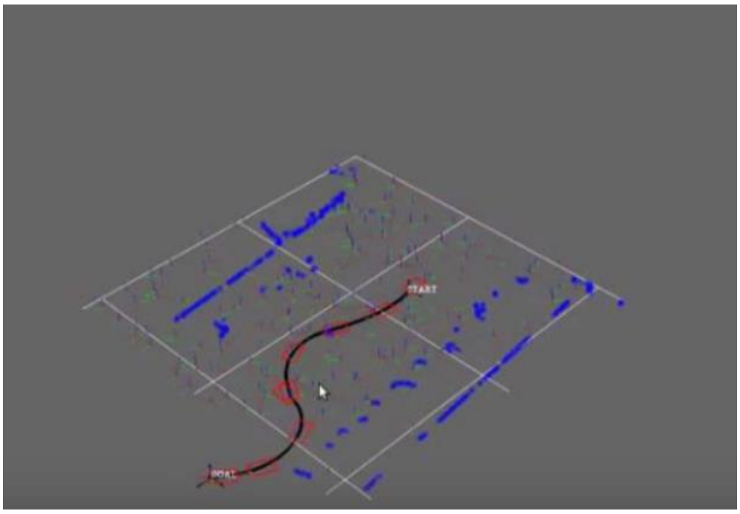
Path Planning

Once the waypoints are obtained, a path has to be planned and followed to the selected waypoint. For this the Timed Elastic Band (TEB) planning algorithm has been used. This algorithm is extremely efficient in navigation on a small like lawns and rooms.

The TEB merges the states, control inputs and time intervals into a joint trajectory representation which enables planning of time-optimal trajectories in the context of model predictive control. Model predictive control integrates the planning of the optimal trajectory with state feedback in the control loop. The TEB approach formulates the fixed horizon optimal control problem for point-to-point transitions as a nonlinear program.

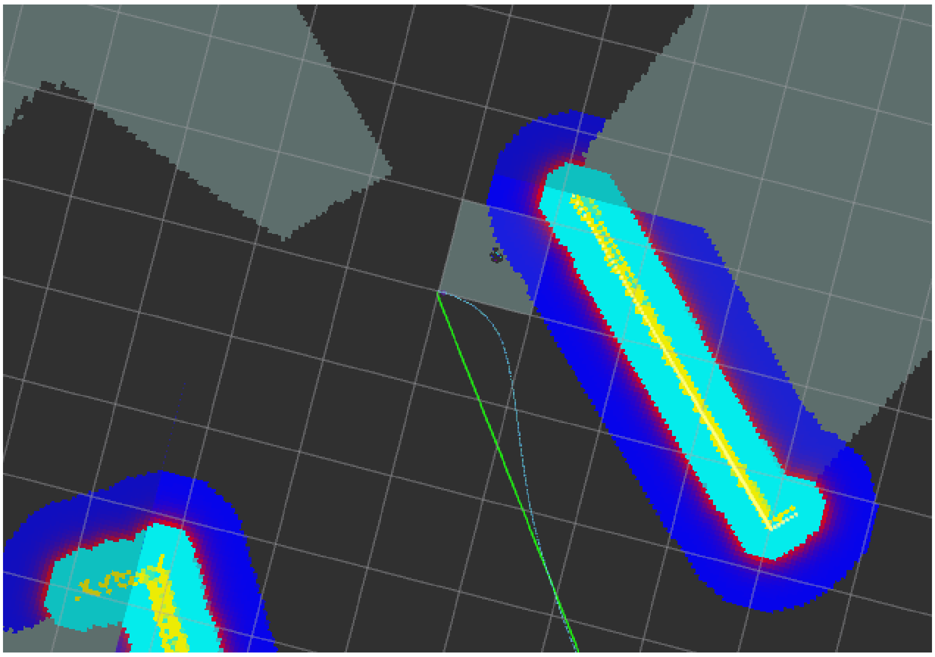
A comparative analysis of the TEB approach was performed with state-of-the-art approaches which demonstrated its computational efficiency. The TEB approach generates a trajectory that approximates the analytical time optimal trajectory in few iterations. This efficiency enables the refinement of the planned state and control sequence within the underlying closed-loop control during runtime.





Another example of Planner:

Here the blue part is generated by the planner and the green line is the line joining current location to the target. Yellow line is the obstacle and the region around it is the inflation.



References

- https://www.arduino.cc/
- http://wiki.ros.org/dwa_local_planner
- http://docs.ros.org/lunar/api/robot_localization/html/index.html
- http://ieeexplore.ieee.org/document/7331052/
- Shigley's Mechanical Engineering Design - Book by J. Keith Nisbett and Richard G. Budynas
- https://www.invensense.com/products/motion-tracking/6-axis/mpu-6050/
- Theory of Mechanisms and Machines – Book by Amitabha Ghosh and A K Mallik