ME3103 Mechanical Systems Design
Greengineers - Grass Bot

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Introduction

Grass cutting is labor-intensive and working conditions are harsh. Automated lawn mowers are an improvement but have many shortcomings.

We aim to design an automated grass cutting robot that is able to trim a football field in the shortest time possible with the push of a button, thus reducing the labour requirement and enhancing efficiency.

Yomband YB-M13-320

PROS	CONS

• Reduces manpower required
• Operates beyond office hours
• Significantly less noisy
	• Installation of boundary wires
	• Inefficient
	  • random movement
	  • cutting width
	  • movement speed

The Problem

Navigation

We require a navigation system that does not involve tedious physical set-up

Mowing Capability

We aim for the robot to be able to cover half a football field within its operating timespan

Power Management

The robot needs to have enough battery capacity for at least three hours of continuous operation

The Solution

RTK-enabled GPS navigation

GPS navigation allows for guided operation without physical set-up. RTK boosts GPS precision to our requirements

Battery selection

Using a battery with higher capacity would allow for longer operation hours

Drivetrain modification

Modifying the drivetrain to increase the Grassbot's movement speed increases cutting speed

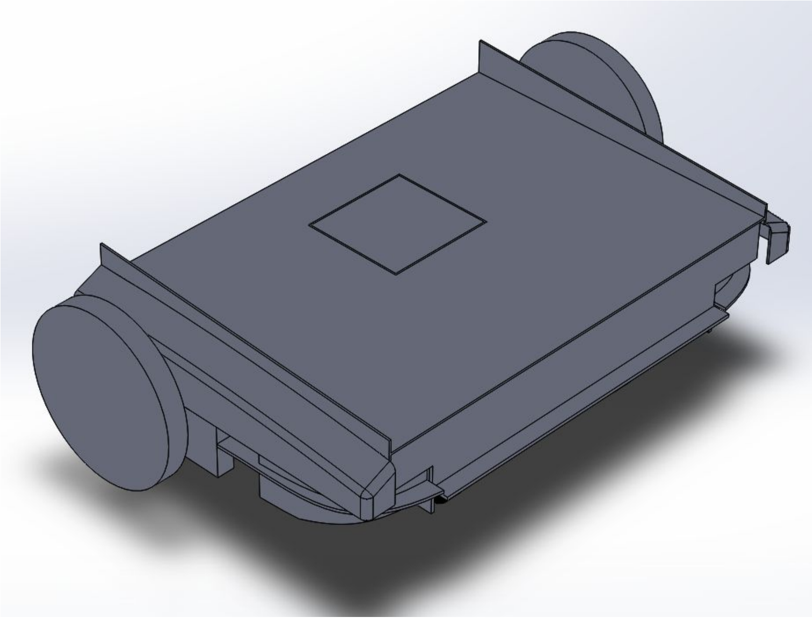
Chassis modification

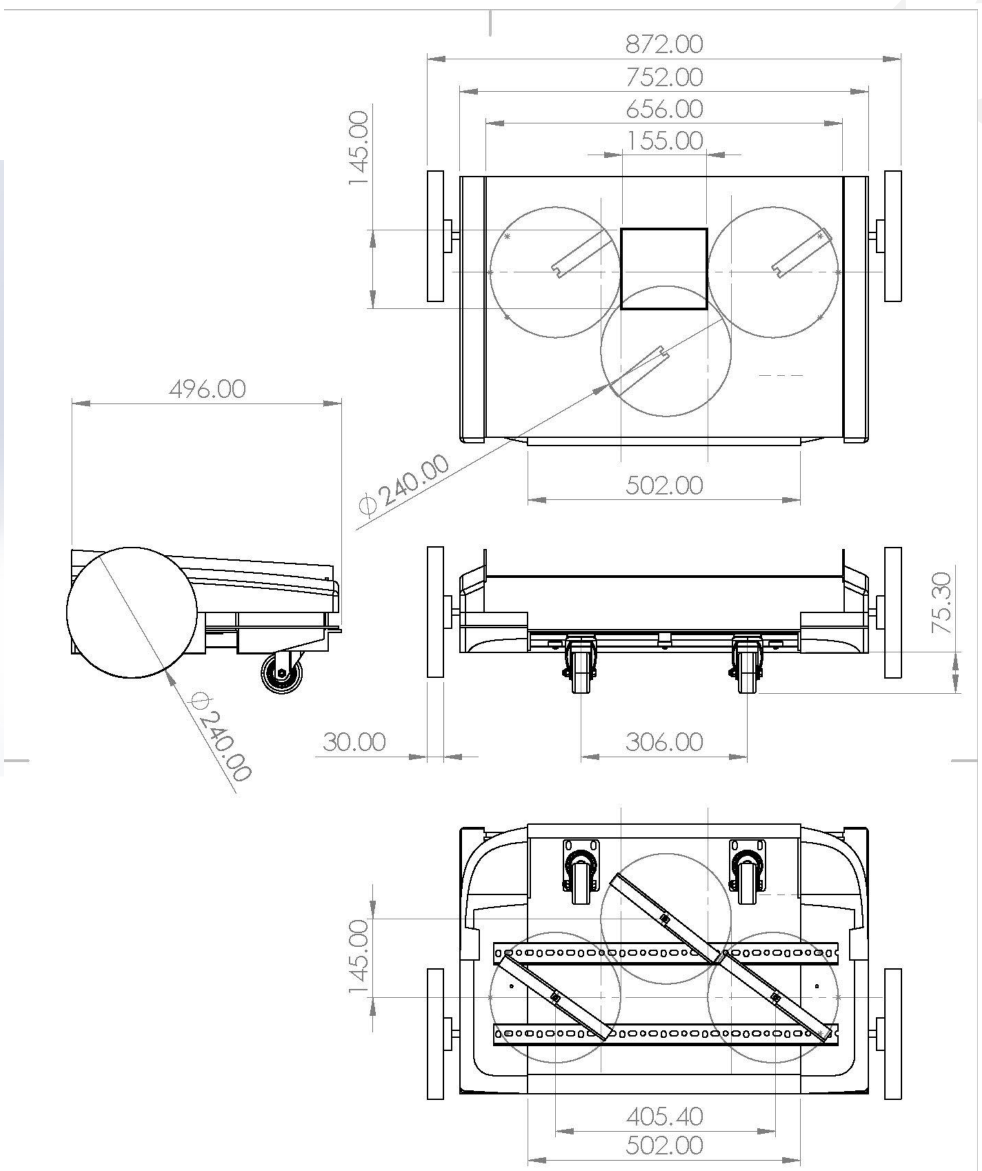
Widening the cutting area increases the Grassbot's working area

Redesigned cutting blades

Cutting blades are optimized to take advantage of the increased cutting area

Grassbot





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Drivetrain

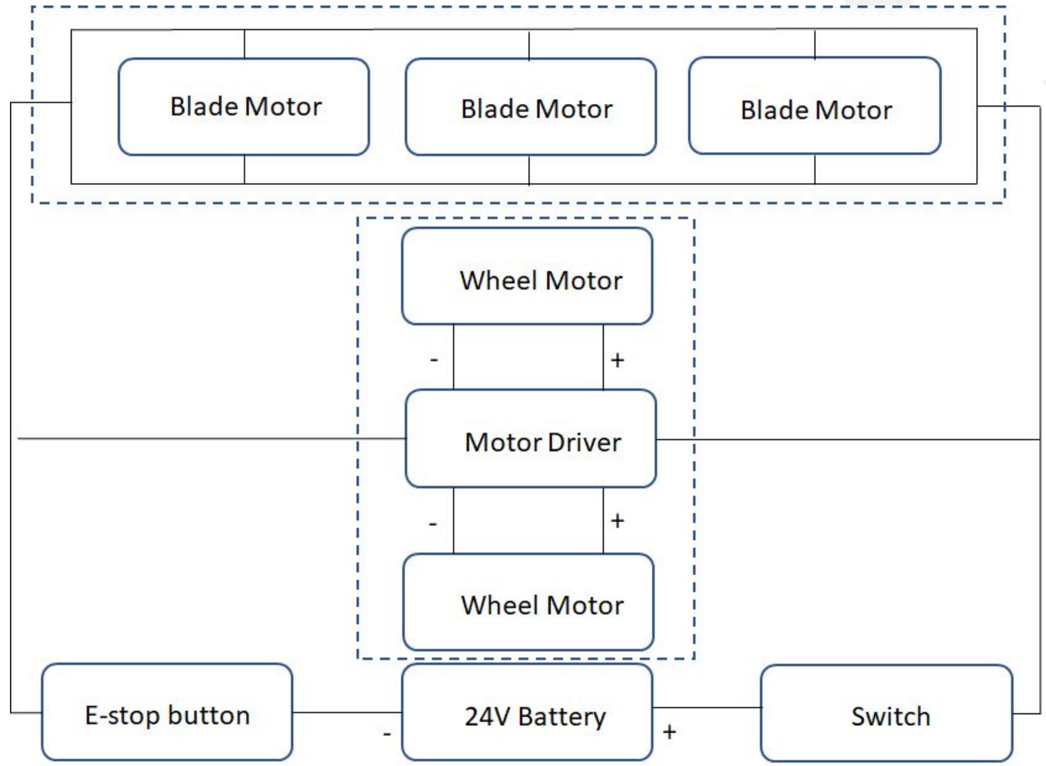
Specification

Battery: 24v 6.6Ah

Wheel motor: 24v 25W, 28 rpm

Blade motor: 24v 6000 rpm

Motor driver: 24v 3A



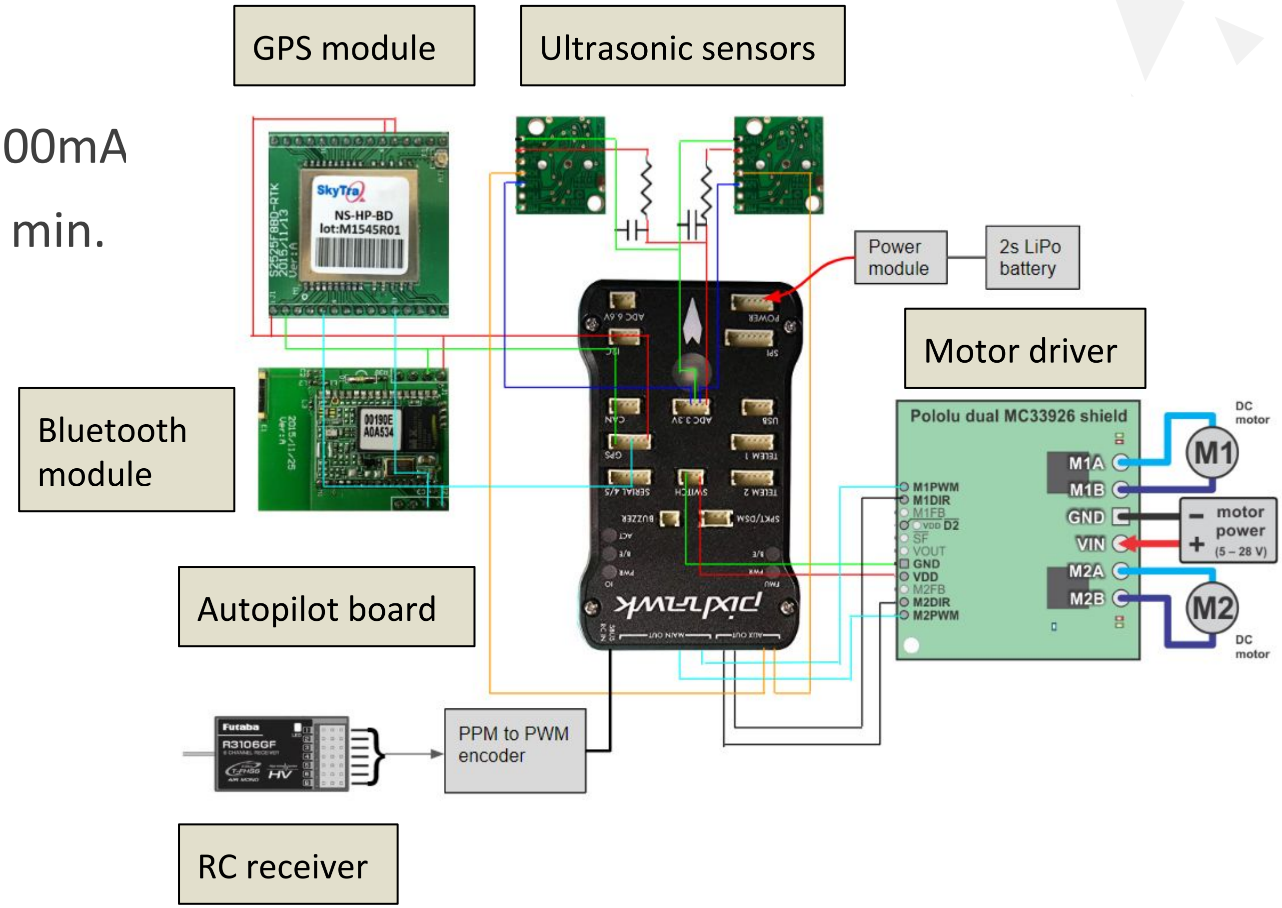
Electronics

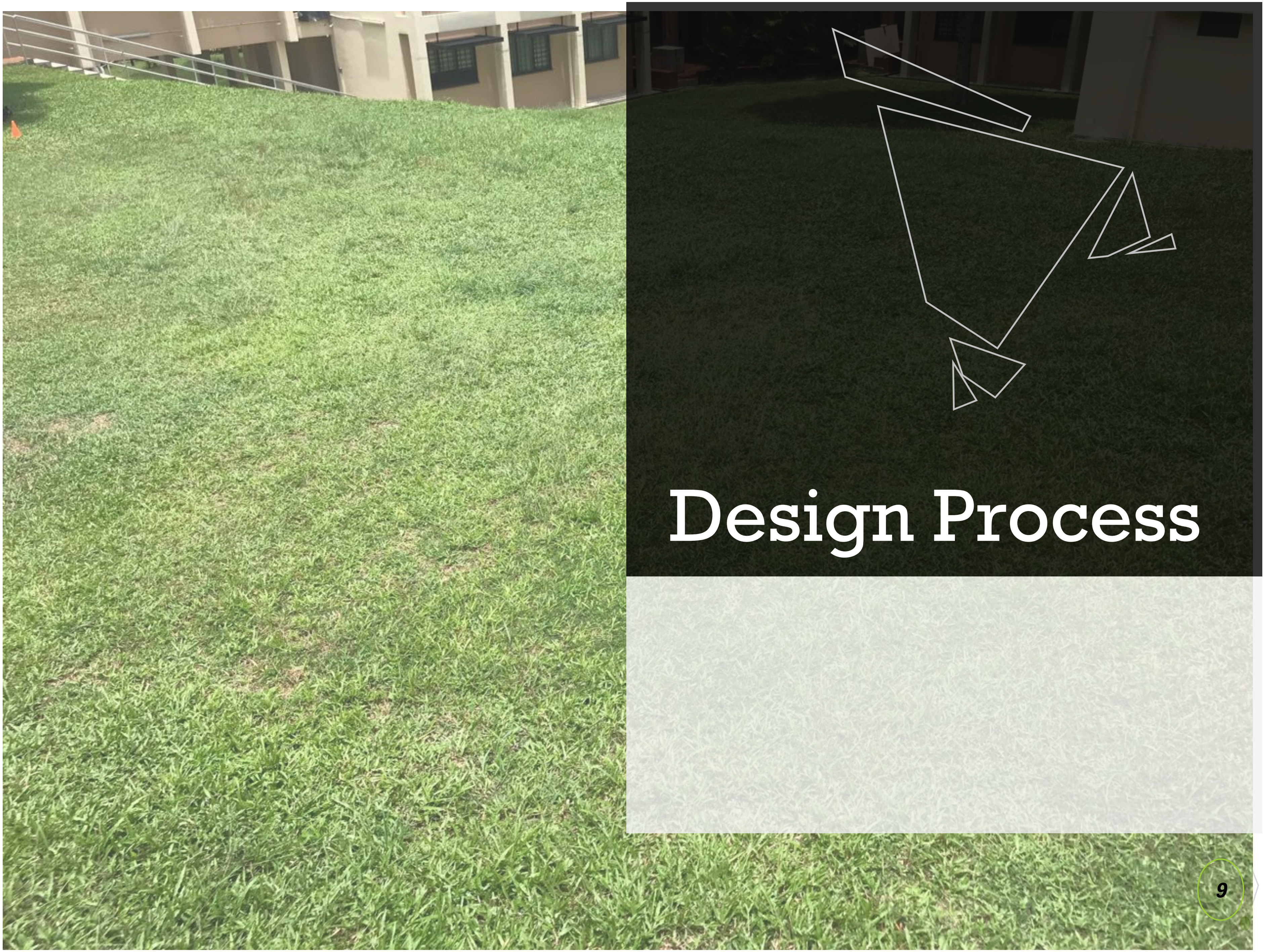
Specification

Battery: 2s Li-Po, 1300mA

RC Tx/Rx: 6 channel min.

GPS: RTK enabled



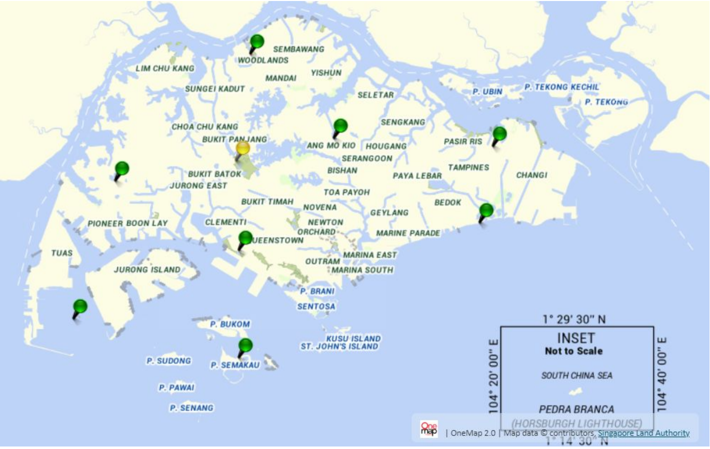


Design Process

Navigation system

GNSS

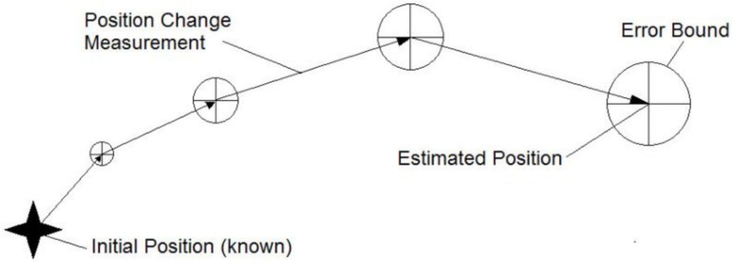
- Works in open areas
- Accuracy depends on satellite coverage
- RTK technology enables centimeter-level accuracy



Source: Singapore Land Authority. "Sensor Map." Retrieved Apr 2019. https://www.sla.gov.sg/SIRENT/Map/SensorMap.aspx

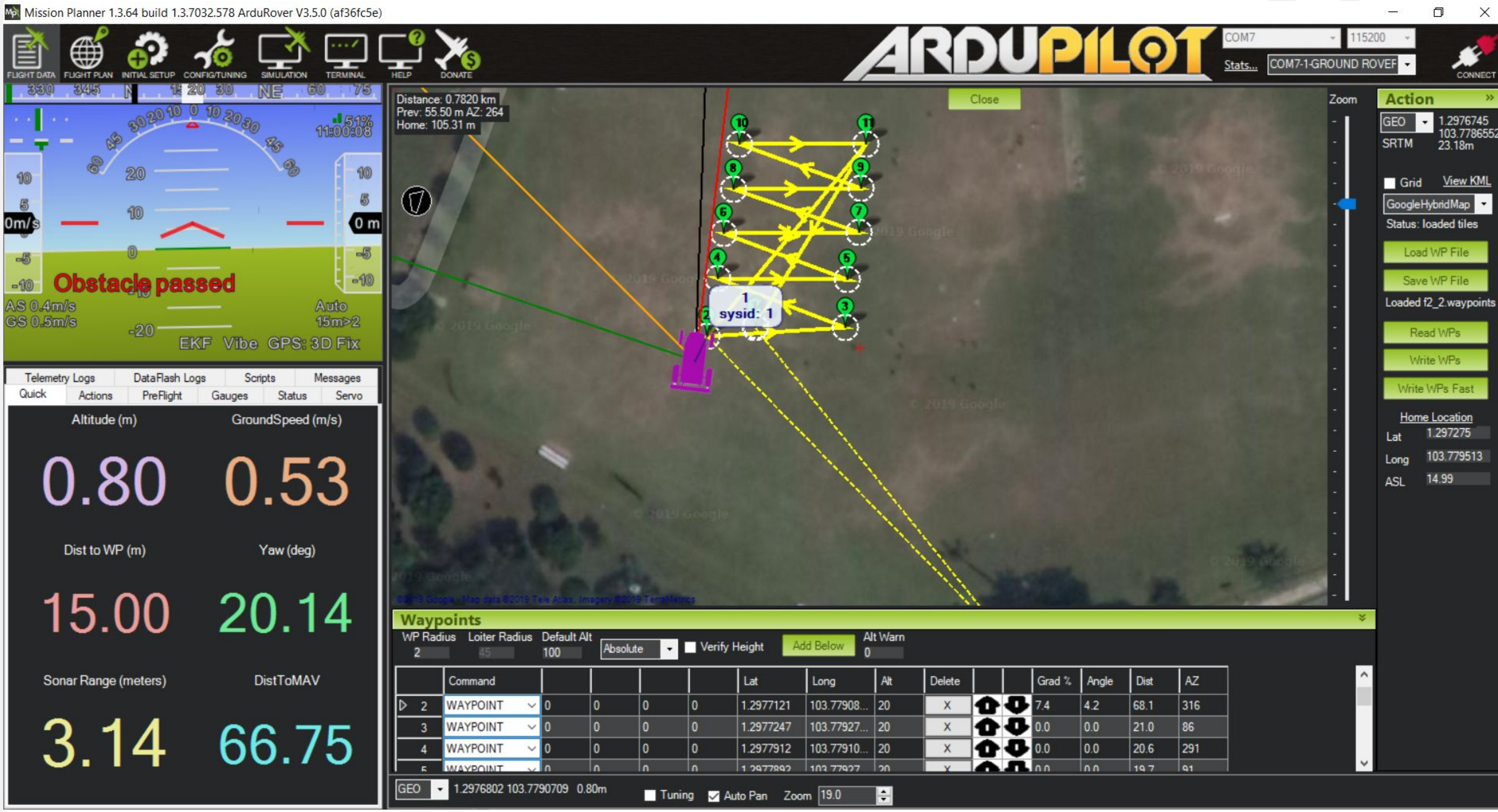
Dead reckoning

- Works anywhere
- Prone to cumulative errors
- Difficult to implement in uneven terrain due to wheel slip



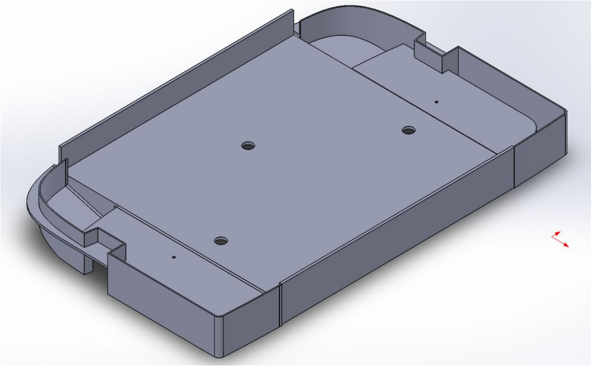
Source: Alessandro Benini. "Localization and Navigation of Autonomous Systems in Complex Scenarios." Oct 2010. doi: 10.13140/RG.2.2.17142.40007

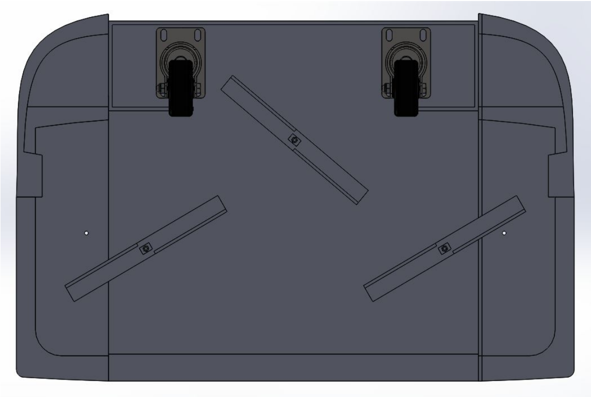
ArduPilot autopilot system



Mission planner UI. Users set the route (shown in yellow with green waypoints) for the robot to follow.

Chassis Modification

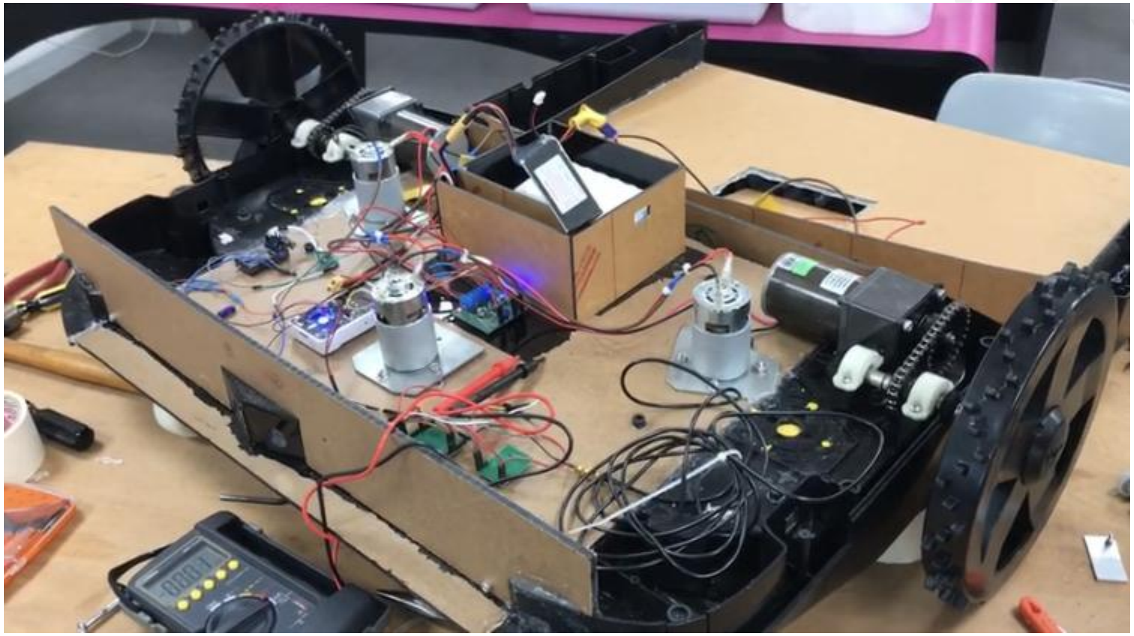




- Increase in cutting width→ Increase in overall cutting efficiency
- Bigger blade system
- Material Selection

Chassis Modification

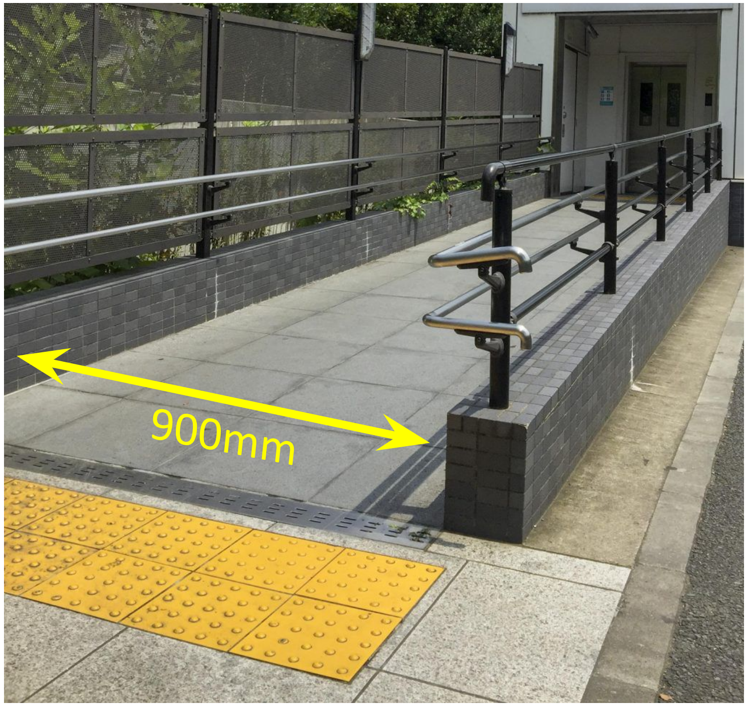
- Battery compartment
- Sensor housing
- Waterproofing and combining



Chassis Modification - Key Considerations

i. Cutting Width Dimensions

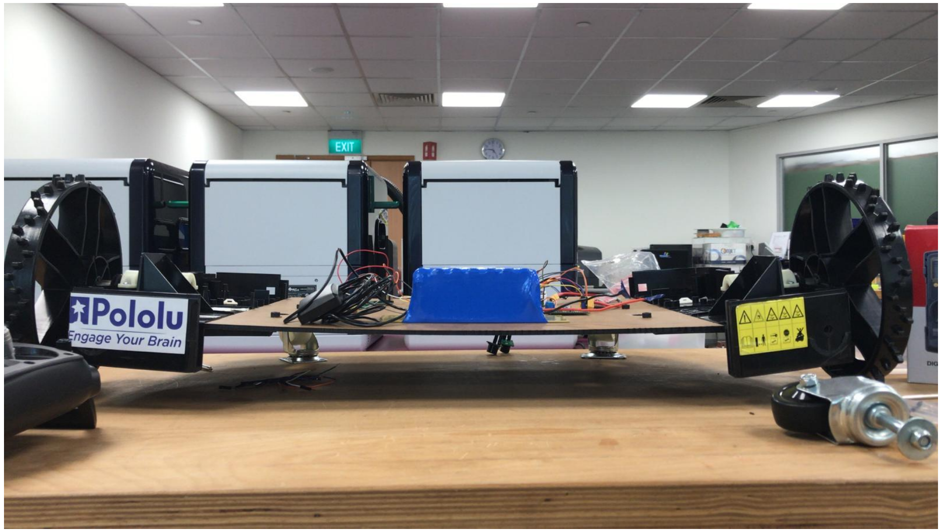
- Based on BCA Code on Accessibility in the Environment 2013
- Can be wheeled around access paths
- Solidworks to determine optimal cutting width (64.5cm)



Chassis Modification - Key Considerations

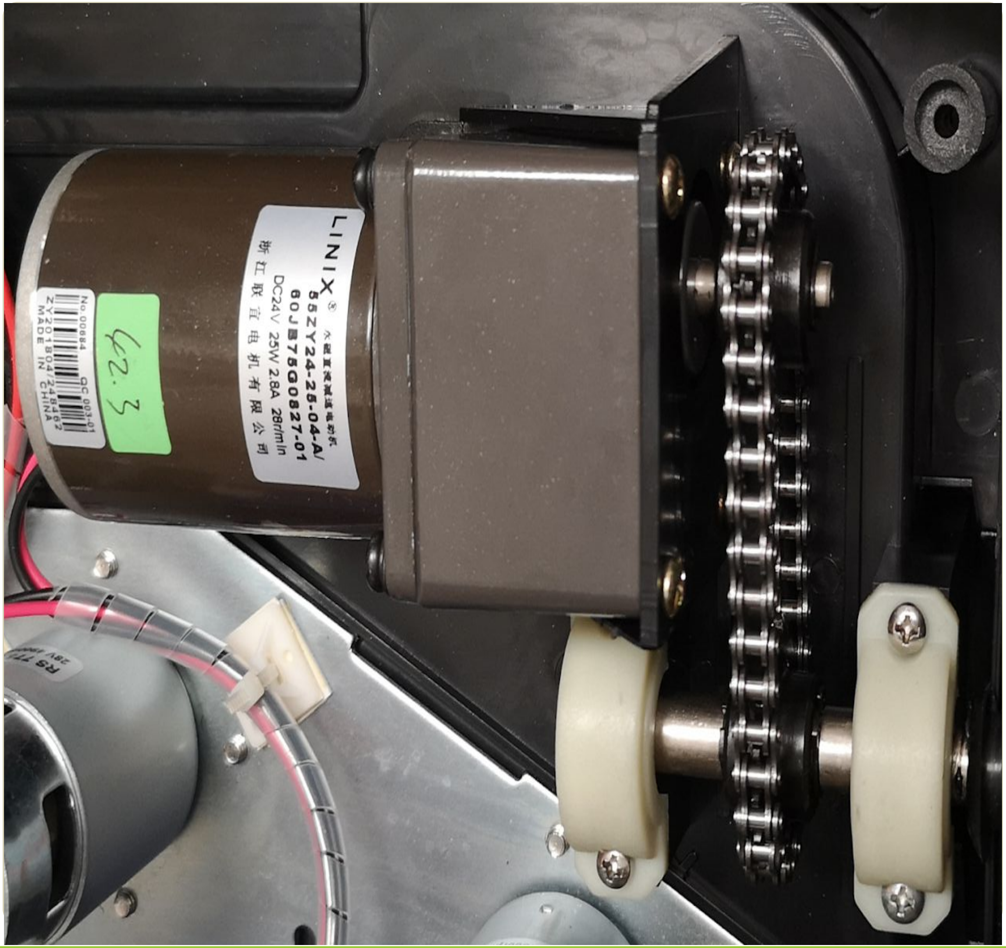
ii. Load Distribution

- Bending of the acrylic component
- Finite Element Analysis to determine estimated deformation value (0.0188cm)
- Steel angled bars to reinforce overall structure



To Increase Mowing Efficiency

Increasing Movement Speed



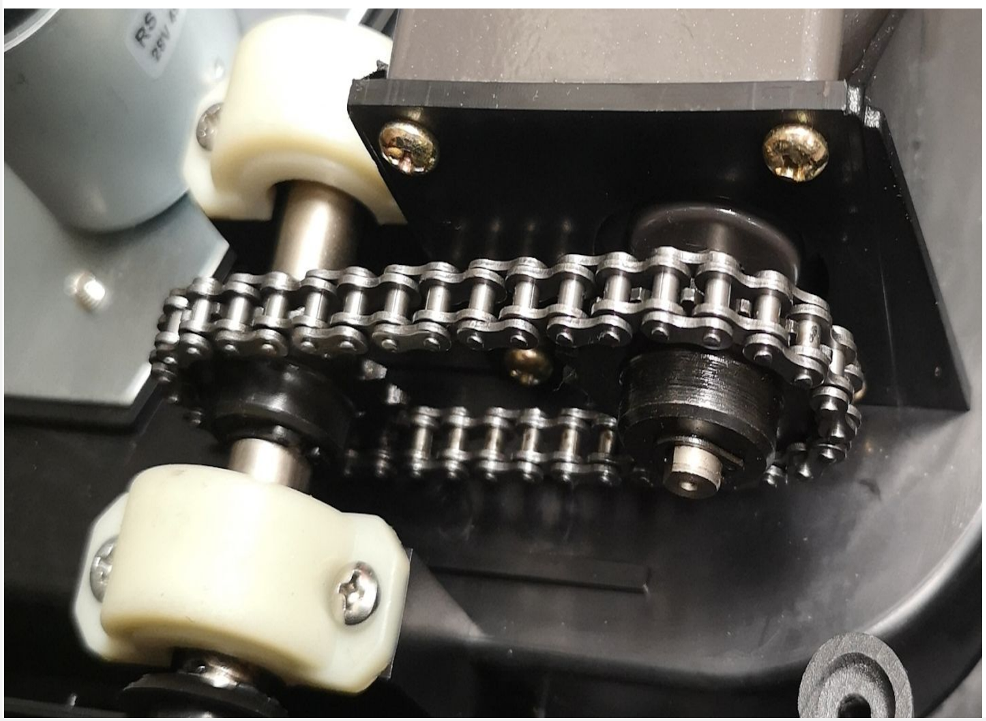
Possible solutions?

- Changing of motor
- Utilising mechanical advantage of gear system

Modifying Sprocket Gear System

$$\text{Gear Ratio} = \frac{\text{No of Teeth in Driven Sprocket}}{\text{No of Teeth in Driver Sprocket}} = \frac{RPM_{Motor}}{RPM_{Wheel}}$$

$$RPM_{Wheel} = RPM_{Motor} \times \frac{\text{No of Teeth in Driver Sprocket}}{\text{No of Teeth in Driven Sprocket}}$$



- **Decrease Teeth of Driven Sprocket**
- **Increase Teeth of Driver Sprocket**

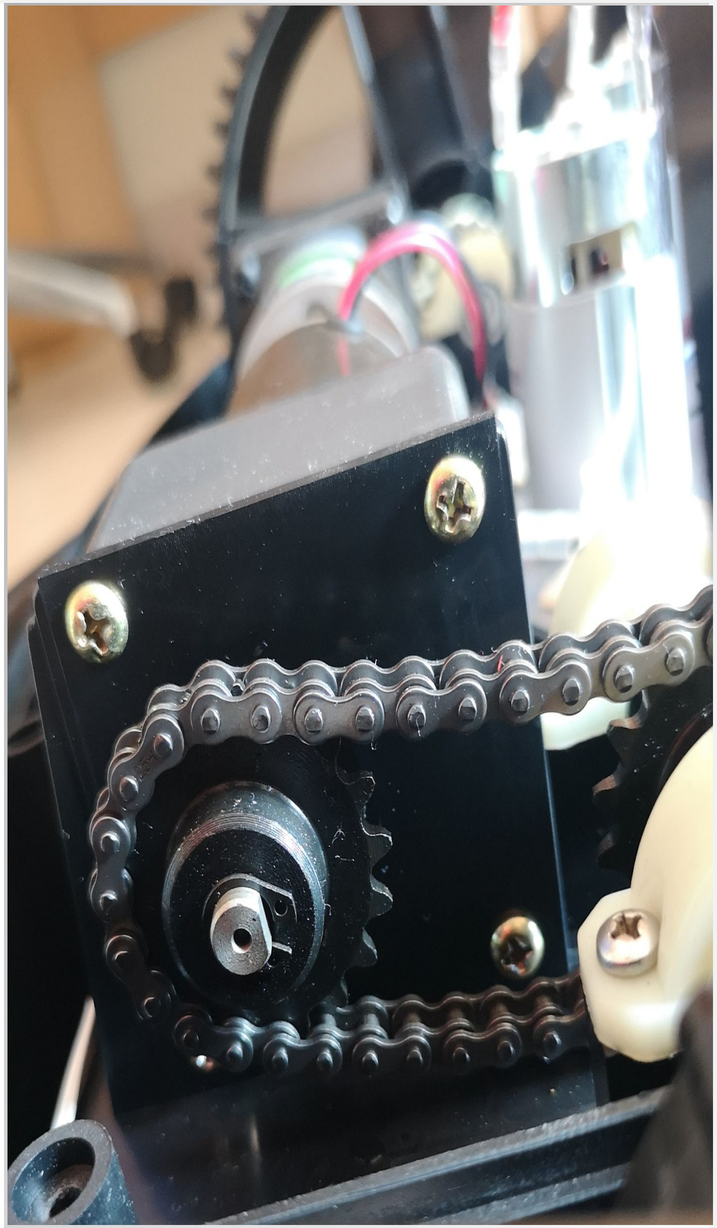
Sprocket Selection Criteria

Minimum Shaft Hole Diameter

Sprocket Outer Diameter

Torque Reduction

56mm sprocket with 26 teeth



$P = F \times v$

$P = F \times RPM \times \frac{c}{60}$

$F = \frac{P}{RPM} \times \frac{60}{c}$

$F_{Motor} = 71N$ $F_{Wheel} = 47N$ (34% force decrement)

$RPM_{Wheel} = 28 \times \frac{26}{15} \approx 48.5$ (73% speed increment)

$F_{forward\ required} = f \times N$

$F_{forward\ required} = f \times g \times mass$

$F_{forward\ required} = 65N$

$2 \times F_{wheel} > F_{forward\ required}$

$94N > 65N$

P: power (25W)

RPM: round per minute

(motor RPM: 28)

(wheel RPM: 48.5)

F: force

r: radius (12cm)

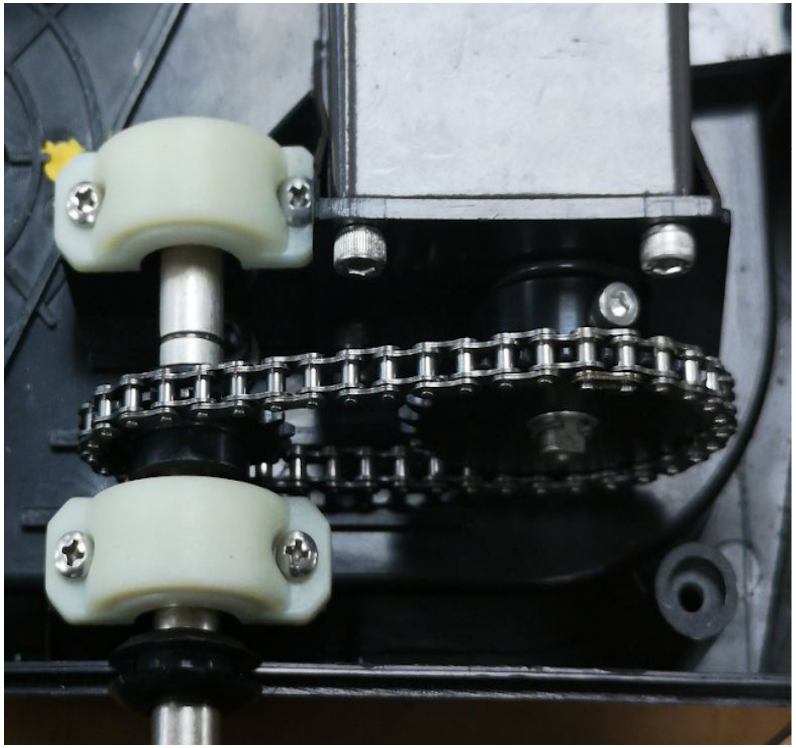
c: circumference ($2\pi r$)

f: friction coefficient of grass

(assume: 0.5)

g: gravitational acceleration

($9.81 m/s^2$)



26 teeth sprocket w ϕ56mm

Speed increment outweigh force reduction.

Battery specifications w.r.t cutting capabilities

Original mower specs:

1/7 of a football field in 3 hours using a 6.6Ah Lithium Ion Battery

Our aim:

½ of a football field in 3 hours

What we did:

2x cutting width (320mm to 640mm)

2x forward speed (to 0.3m/s to 0.6m/s)

Putting things in context:

Our aim will be achieved **only if** the battery can still last 3 hours at the new current discharge rate

Otherwise, battery capacity needs to be increased

Measuring new operating conditions

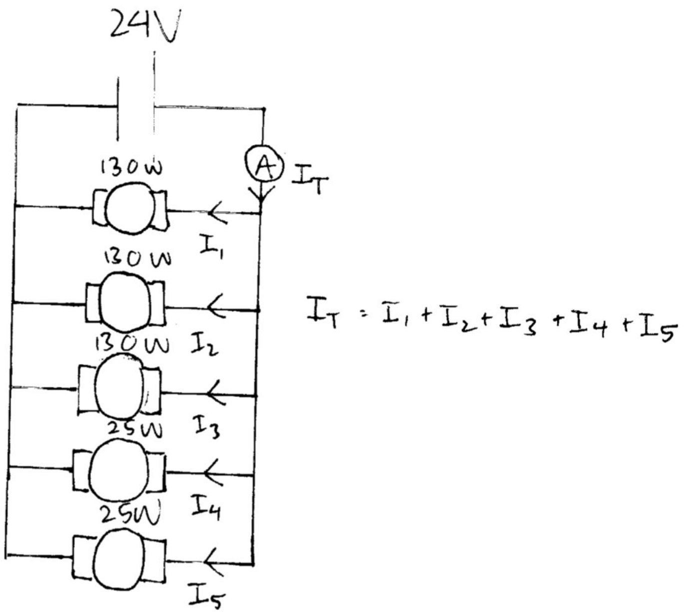


Fig.1: Electronic circuit for motors (blade motors with power 130W and wheel motors with power 25W)

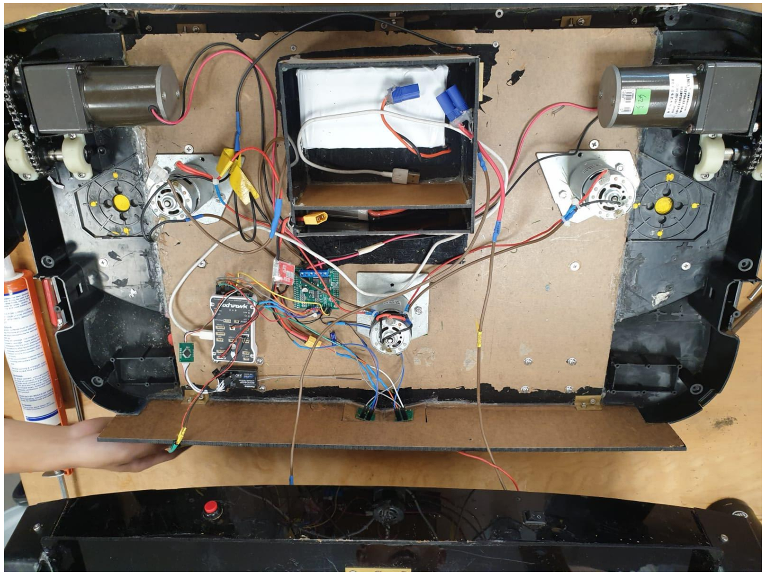


Fig 2: Electronics inside grassbot

Fig 3: Measuring new current discharge rate

We also conducted a battery life test by letting our grassbot to run for 3 hours

Conclusion

-Criteria for 24V 6.6Ah Lithium Ion Battery to be reused:

1) New current discharge rate has to be lesser than 6.6A
2) Battery has to last for a minimum of 3 hours

-Results:

1) New current discharge rate was found to be up to 4A
2) The 24V 6.6Ah lithium ion battery was able to last for at least 3 hours at new operating conditions

-Hence, we do not need to increase the capacity of the 24V 6.6Ah lithium ion battery and it can still be used to power our robot.

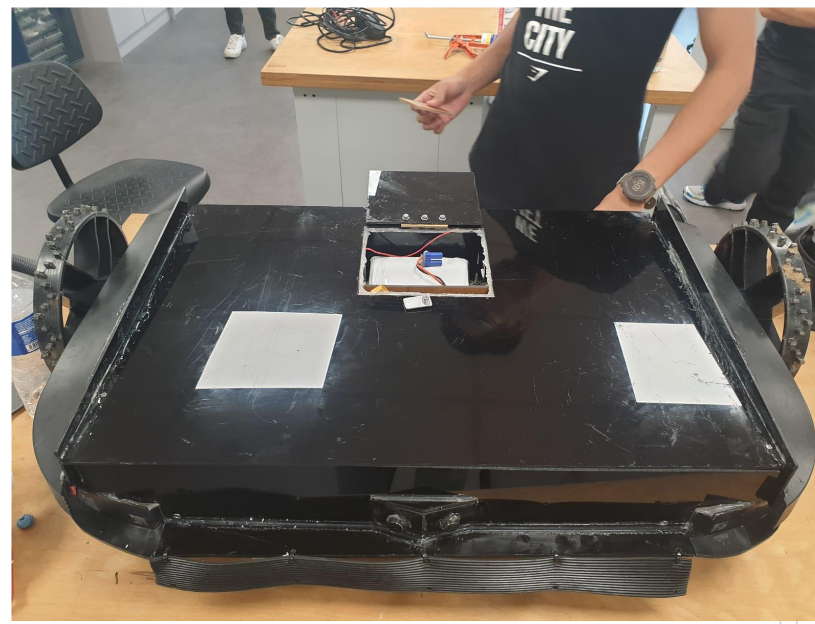
Battery compartmentment design

Before: Built in battery

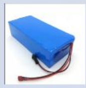
Limitation: have to charge directly i.e cannot plug and play

After: 'Plug and Play' design

Strength: flat battery can be easily replaced with another new fully charged battery

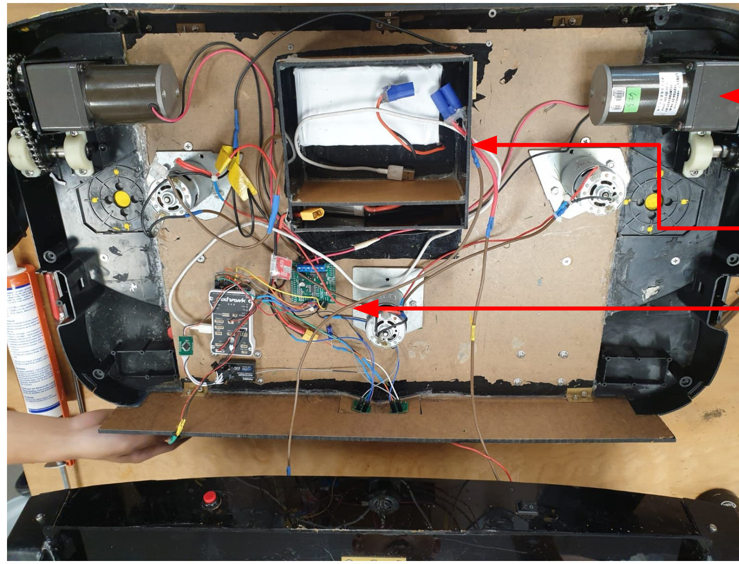


Budget Breakdown

Part #	Part Name	Description	Picture	Cost
1	Chassis Fabrication	Chassis, Wheels, Blades		$100.00
2	Blade motors	3x Machifit 895 motor		$23.47
3	Wheel motors	24V 25W Linix DC Motor		$300
4	Sprocket & Chain	Monotaro		$48.96
5	Autopilot Board	Pixhawk 2.4.8		$82.73
6	GPS - RTK Components	RTK board, bluetooth module, GPS antenna, Antenna Cable		$192.22
7	RC Transmitter/Receiver + PPM encoder	Futaba T6L Sport		$150
8	Ultrasonic Sensors	2x LV-MaxSonar-EZ4-High-Performance Ultrasonic Range Finder		$79.18
9	Lipo Battery + Charger	Imax B3 Pro Lipo Charger		$30
10	Lithium Ion Battery	24V 6.6Ah Lithium Ion Battery		$200
11	Motor Driver	Pololu Dual MC33926 Motor Driver Shield for Arduino		$81.05
	Total			$1287.61

Total	$1287.61

Final Product



Drivetrain modification

Battery selection

RTK-enabled GPS navigation system

Chassis modification

Extension of cutting width

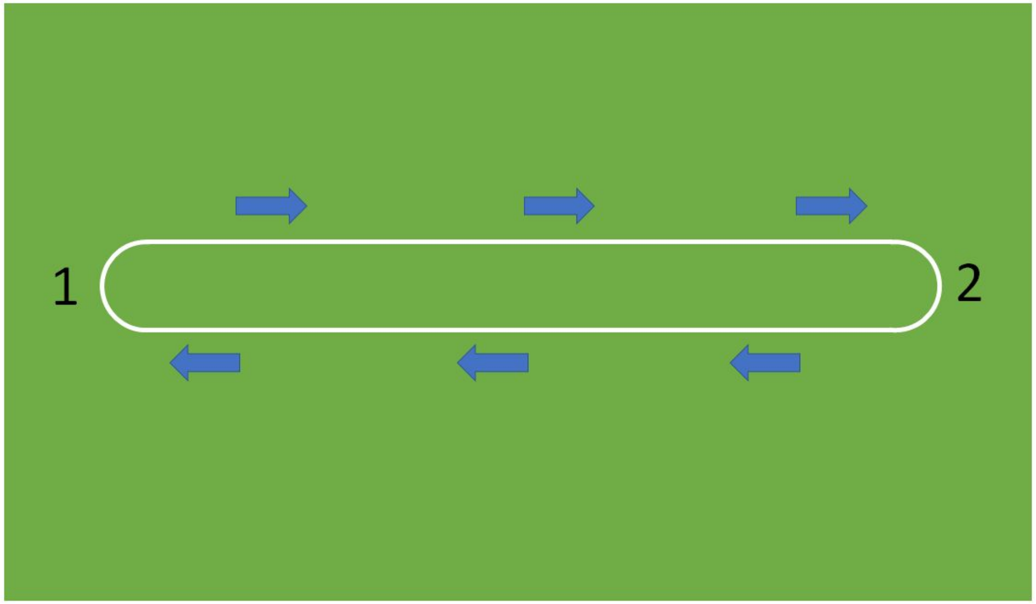
Testing

1. Navigation
 - Auto-pilot mode in Mission Planner
 - RTK accuracy (SiReNT Subscription)

2. Mowing Capabilities
 - Grass-cutting capabilities
 - Max mowing speed - 2.4km/h => 0.6m/s

Testing

3. Power Management
- Testing of battery operation time
- Auto-pilot mode used to run the robot continuously
- Record the movement at 30-minute intervals



The Problem

Navigation

We require a navigation system that does not involve tedious physical set-up

Mowing Capability

We aim for the robot to be able to cover half a football field within its operating timespan

Power Management

The robot needs to have enough battery capacity for at least three hours of continuous operation


Thank You