6024

MARCH 2018
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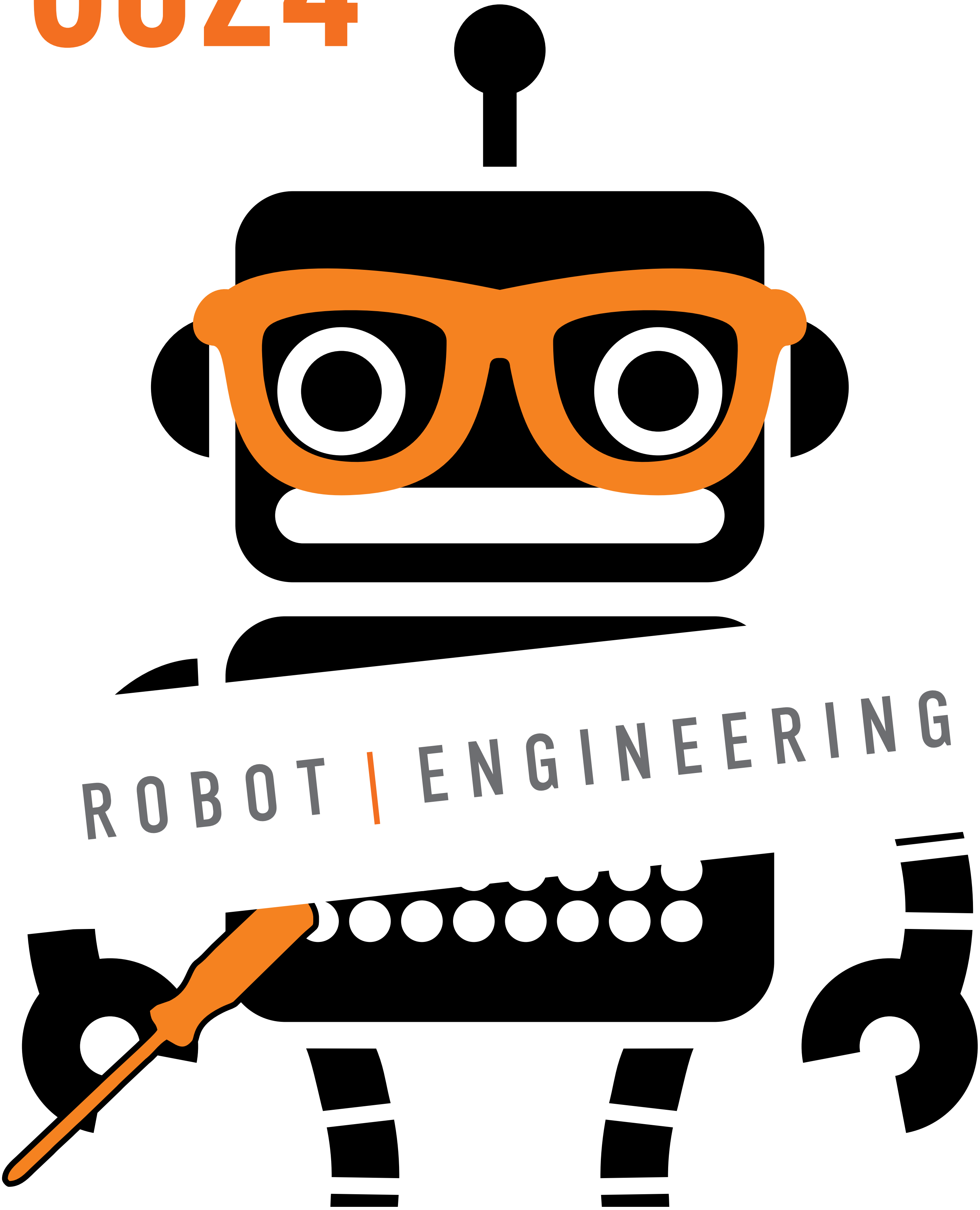


MARCH, 2018
FREE FOR CIRCULATION IN FRC

Focus and Simplicity.

Simple can be harder than complex:
You have to work hard to get your thinking clean to make it simple. But it's worth it in the end because once you get there, you can move mountains.

"When you want to know how things really work, study them when they're coming apart."

(WILLIAM GIBSON)

TABLE OF CONTENTS

FACTOR

FRC TEAM 6024

Problem Statement

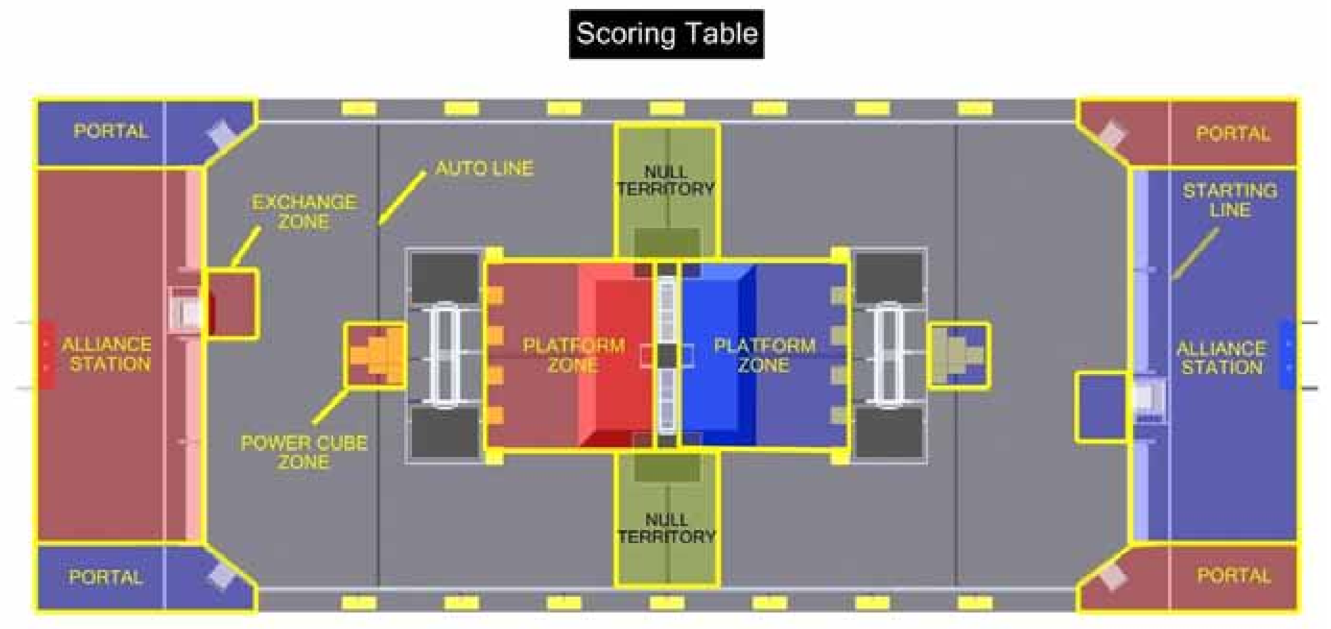
To design, construct and program a robot to:

- Navigate the "Power-Up" Play Field Arena
- Collect and place cubes at different heights in the arena over the play field elements like the "Exchange", "Switch" and the "Scale"
- Climb the "rung" on the "Scale"

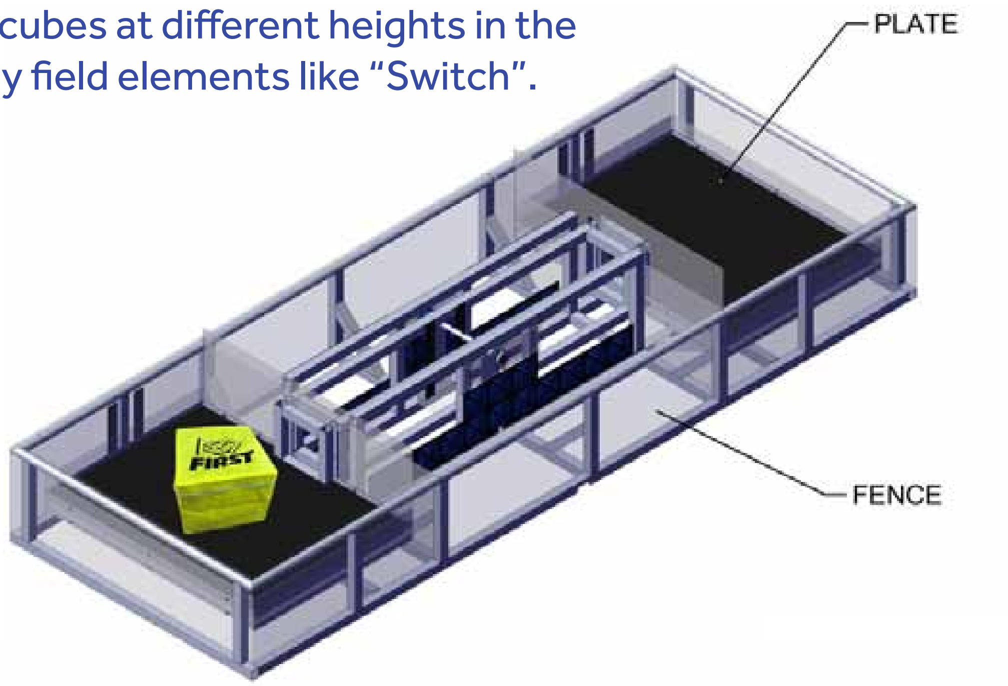
Missions To Be Achieved:

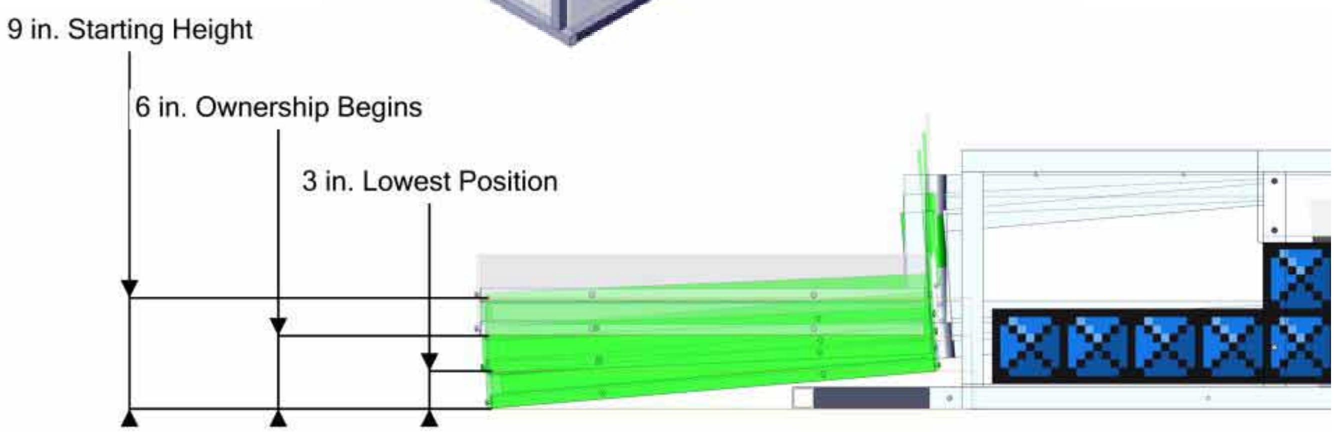
- Cross the auto line during the autonomous play
- Deliver the Power Cube into the Switch or the Scale during the autonomous play
- Control the Switch by placing the Power Cube on to the Switch Plate for as much time as possible during the Tele-Op period
- Control the Scale by placing the Power Cube on to the Scale Plate for as much time as possible during the Tele-Op period
- Deliver the Power Cubes through the exchange to the Human Players who then place them into the Vault earning the Power-Ups to gain temporary advantage during the match
- Climb the Tower of the Scale

Navigate the “Power-Up” Play Field Arena.

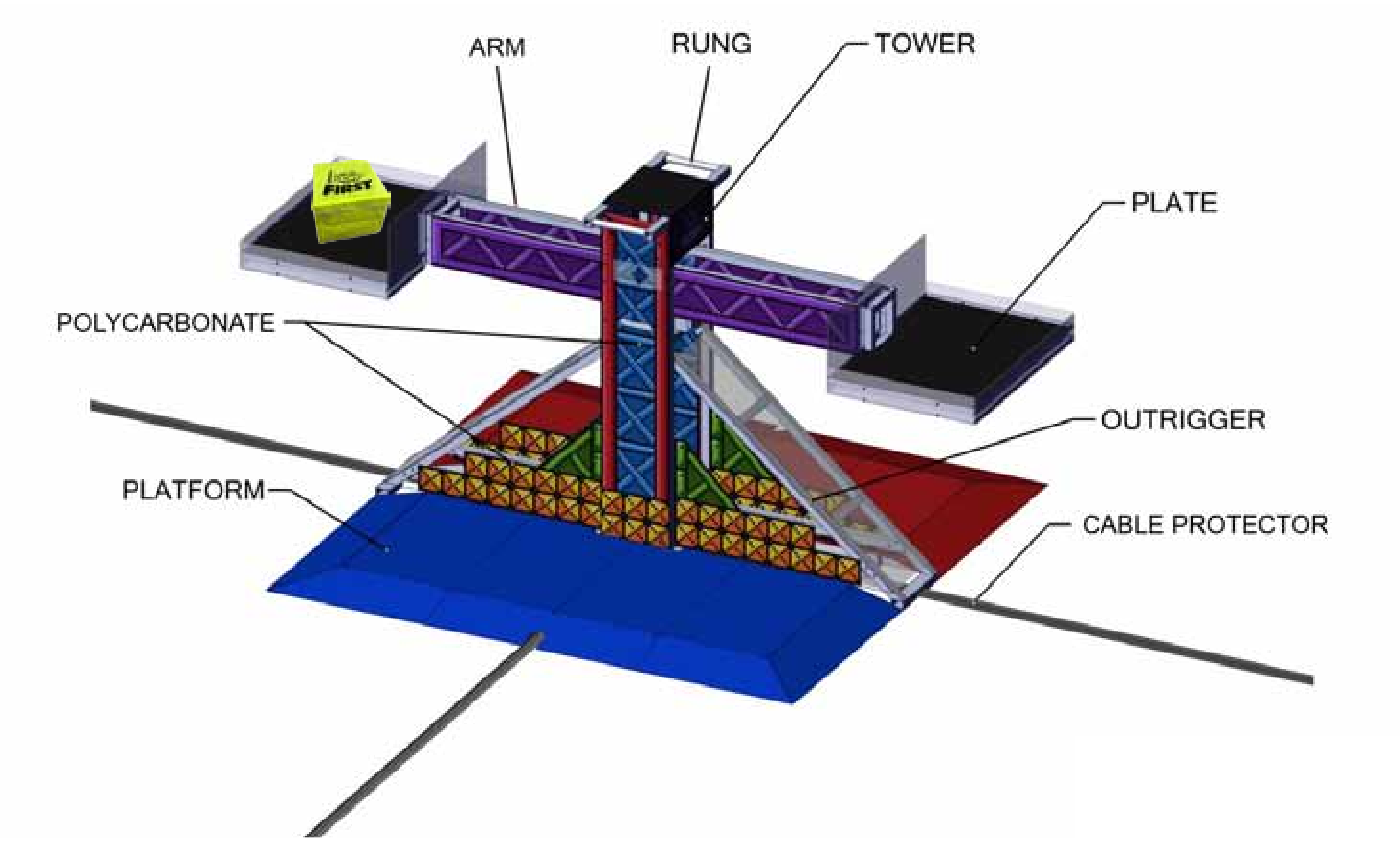


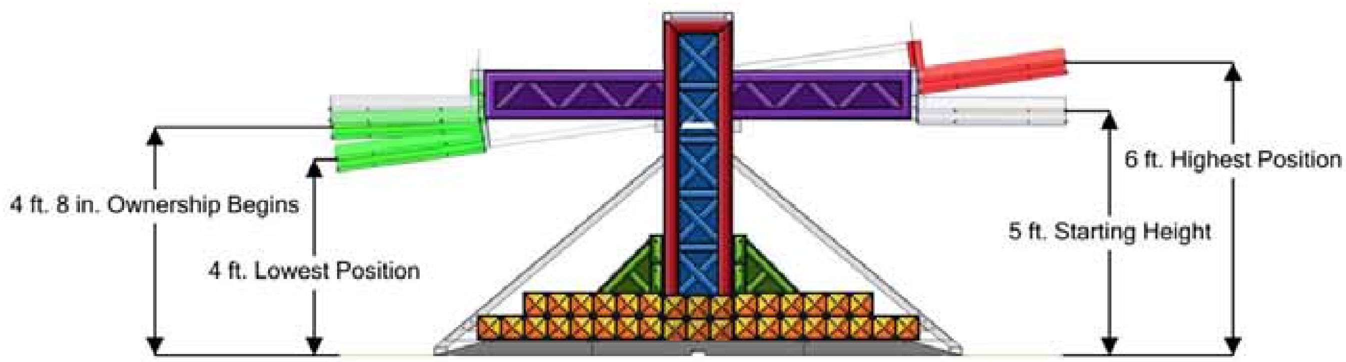
Collect and place cubes at different heights in the arena over the play field elements like “Switch”.



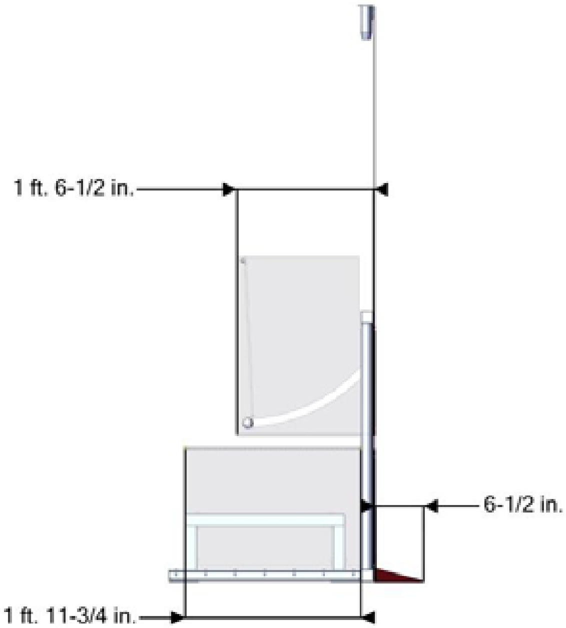


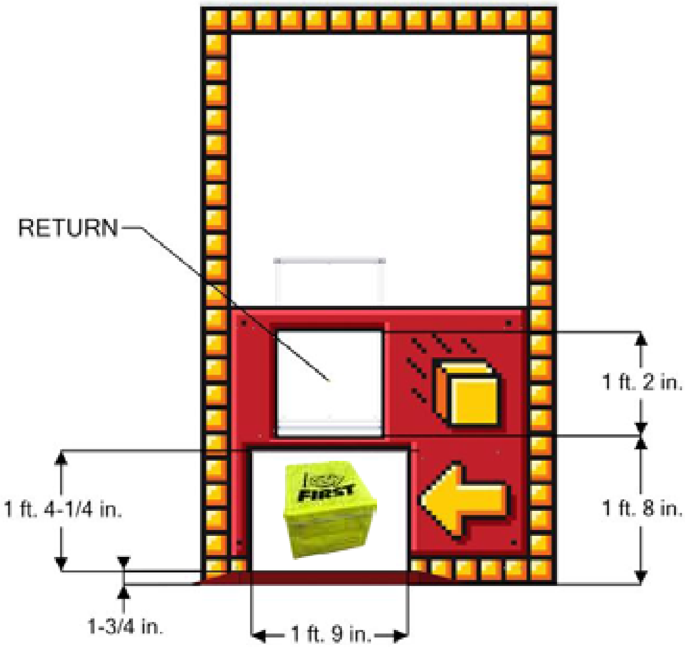
Collect and place cubes at different heights in the arena over the play field elements like the "Scale"



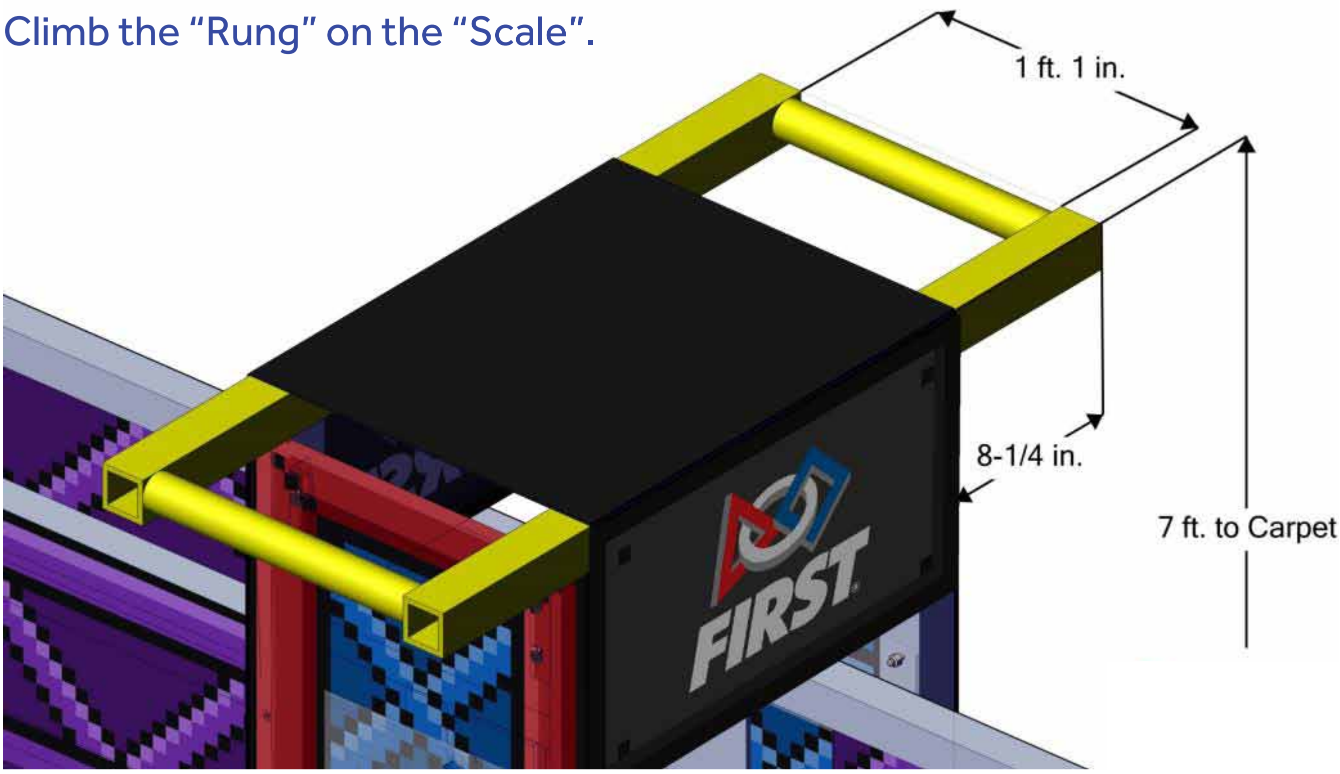


Collect and place cubes at different heights in the arena over the play field elements like the "Exchange"





Climb the "Rung" on the "Scale".



Constraints:

- Max Height = 55"
- Max Width = 28"
- Max Length = 33"
- All components should be within frame perimeter
- Max robot weight = 120 lbs
- Types of motors to be used
- Bumper specification
- Total cost of the robot

The following design considerations were done:

- Movement between the field elements must be well controlled and quick
- Raising and lowering of the mechanism between 8" to 90"
- Effective cube intake and release mechanism
- Lifting of the Robot

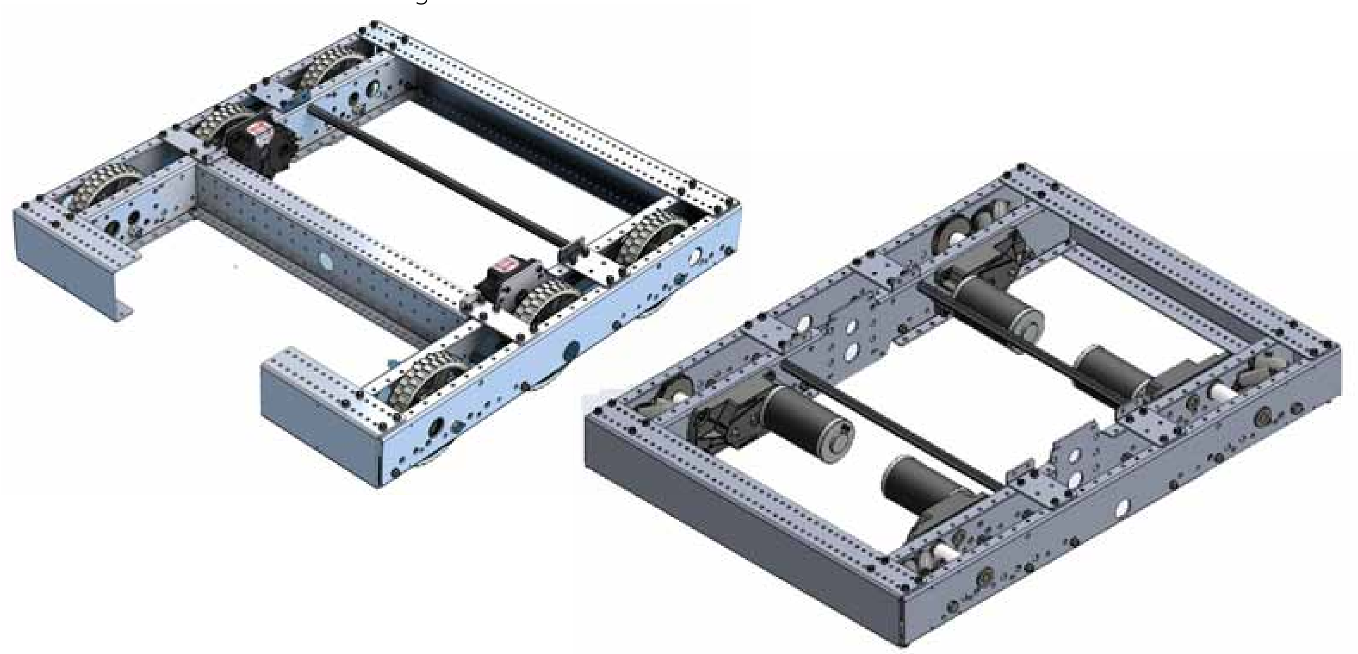
Mechanisms considered:

Scissor Lift and High reach Stacker

Robot Design Evolution:

1) Chassis & Drive Train:

We began with a 4 wheel drive chassis with 4 independent gear boxes and evolved the design to 6 wheel drive chassis with two central gear boxes



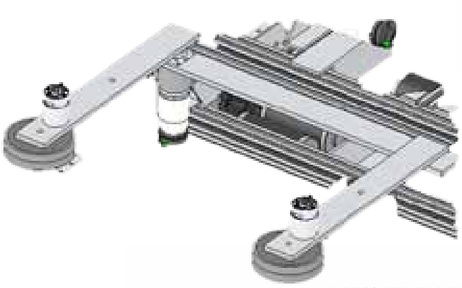
2) We began the collection arm with two fixed arms mounted on a cross bar and the eventually evolved to a design comprising of one fixed arm and one moving arm to have better control and grip for the collection of the Power Cube. Also, we moved from 2 intake wheels to 4 intake wheels with 2 compliant wheels

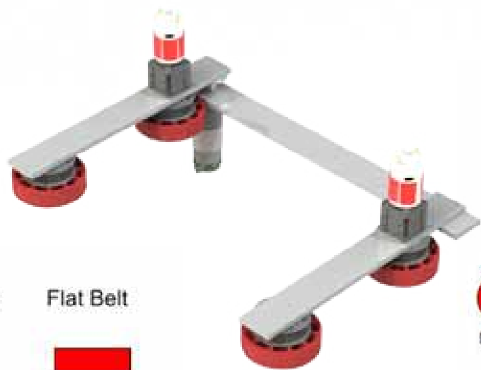
3) For the 2 stage elevator lift, we moved from round section ropes to high tensile flat belt. Subsequently the pulley with round grooves to pulleys with flat grooves

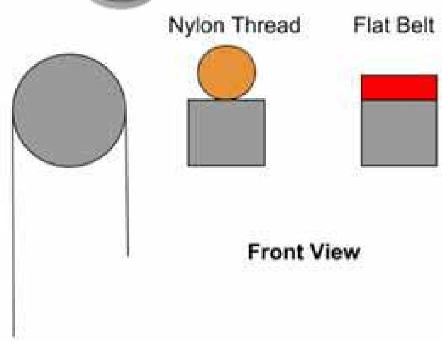
4) We moved from fixed pulleys to pulleys with bearings to reduce the friction and subsequently the effort / torque on gearmotor

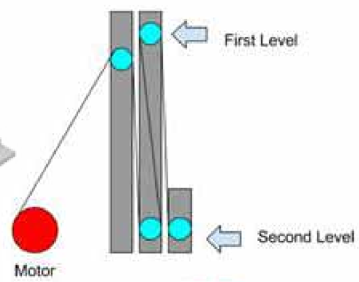
5) For the climbing mechanism, the design of the delivery hooks evolved from a "U" shaped hook assembly to a bell curve shaped assembly offering easy access to the rung

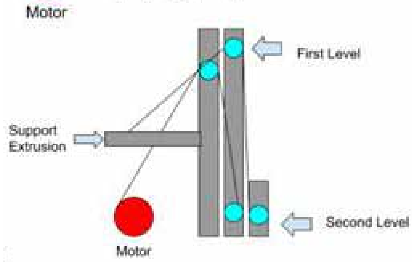
6) We evolved from a single rope going around the winch drum / hook assembly / robot frame to two ropes

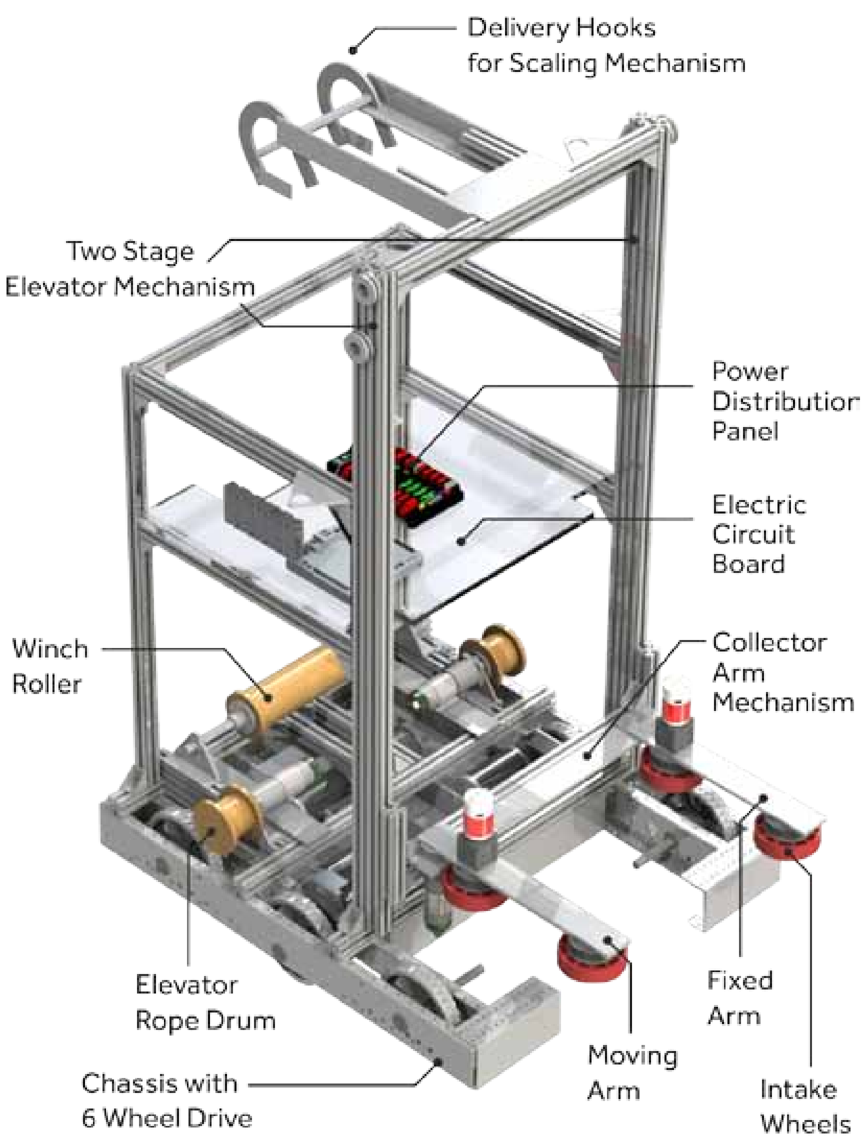












Overall Dimensions:

Length : 32" without bumpers
38.5" with bumpers

Width : 28" without bumpers 33" with bumpers

Height : 54.5"

Weight: 53 kg / 117 lbs

Chassis type:

- **Power Supply Sources**

  - One Power Source: 12V Battery

- **Number Of DC Motors**

  Total: 6 DC Motors

  4 2.5" CIM Motors for the drive base

  2 Andymark 9015 for Collection of the Power Cubes

- **Number Of Geared Motors**

  Total: 4 Gear Motors

  2 PG71 Gear Motor to power the lift mechanism

  1 PG71 Gear Motor for the movable arm

  1 2.5" CIM motor with Banebots BB220 Planetary Gearbox, 64:1 Ratio for scaling

- **Number Of Sensors**

  Total: 5

  2 E4T OEM Miniature Optical Encoder for the drive base

  2 Hall effect two Channel Encoders for the lift mechanism

  navX micro

- **Type Of Controller**

  NI roboRIO

  Raspberry Pi

- **Programming Language**

  Java

  Scaling:

  - 4 hook shaped aluminium plates
  - 2 metal churros
  - 2 standard screws

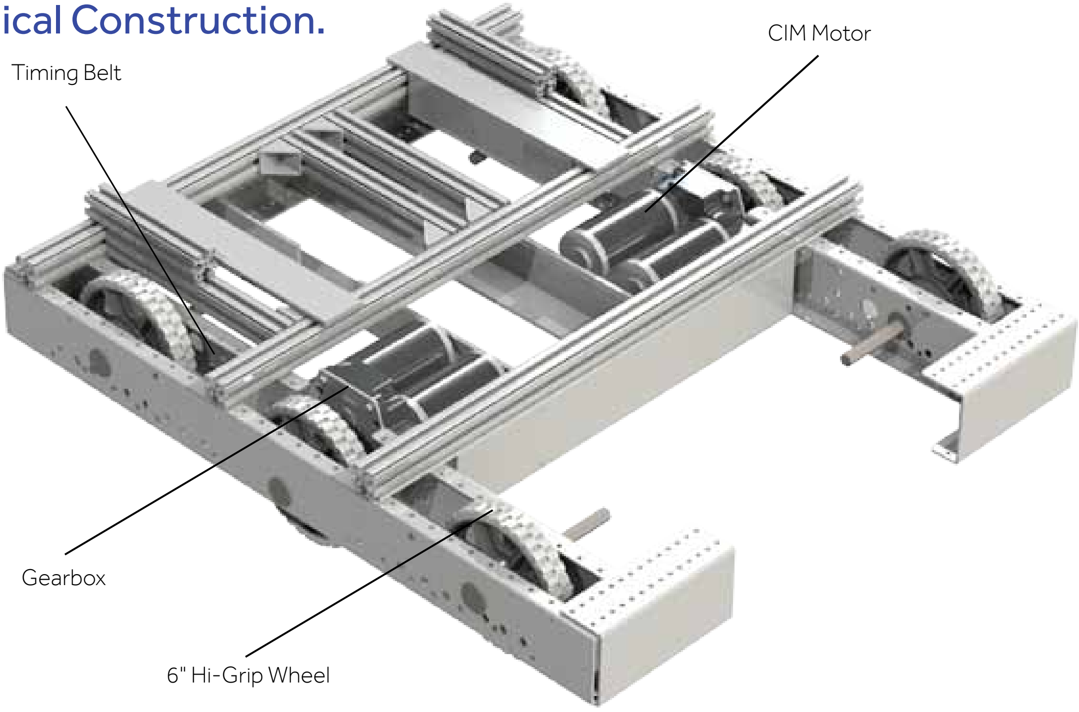
Bill of Materials

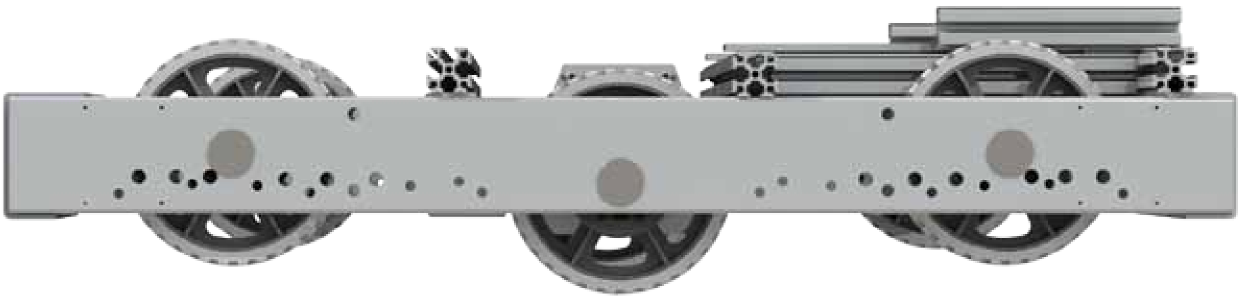
Item Description	Quantity
21" Extrusions	6
30" Extrusion	2
17.75" Extrusions	4
28" Extrusions	3
9.75" Extrusions	4
6.5" Extrusions	2
47.5" Extrusions	4
6" Extrusions	2
PG Motor	3
Redline Motors	2
CIM Motor	5
300" Nylon Thread	1
126" of 3" Flat Belt	1
182" of 5" Flat Belt	1
Angled Brackets	38
Right Angled Slice	8
27.5" Hex Shaft	1
64:1 Gearbox	1
Banebot Gearbox	2
HiGrip Wheels	6
PG Motor Mount	4
CIM Motor Mount	2
Complaint Red Wheels	4
Hex Shaft Collars	8
3.5" diameter 2.5" width Wooden Drum	2
3" diameter 9.5" width Wooden Drum	1

Chassis & Drive Mechanism:

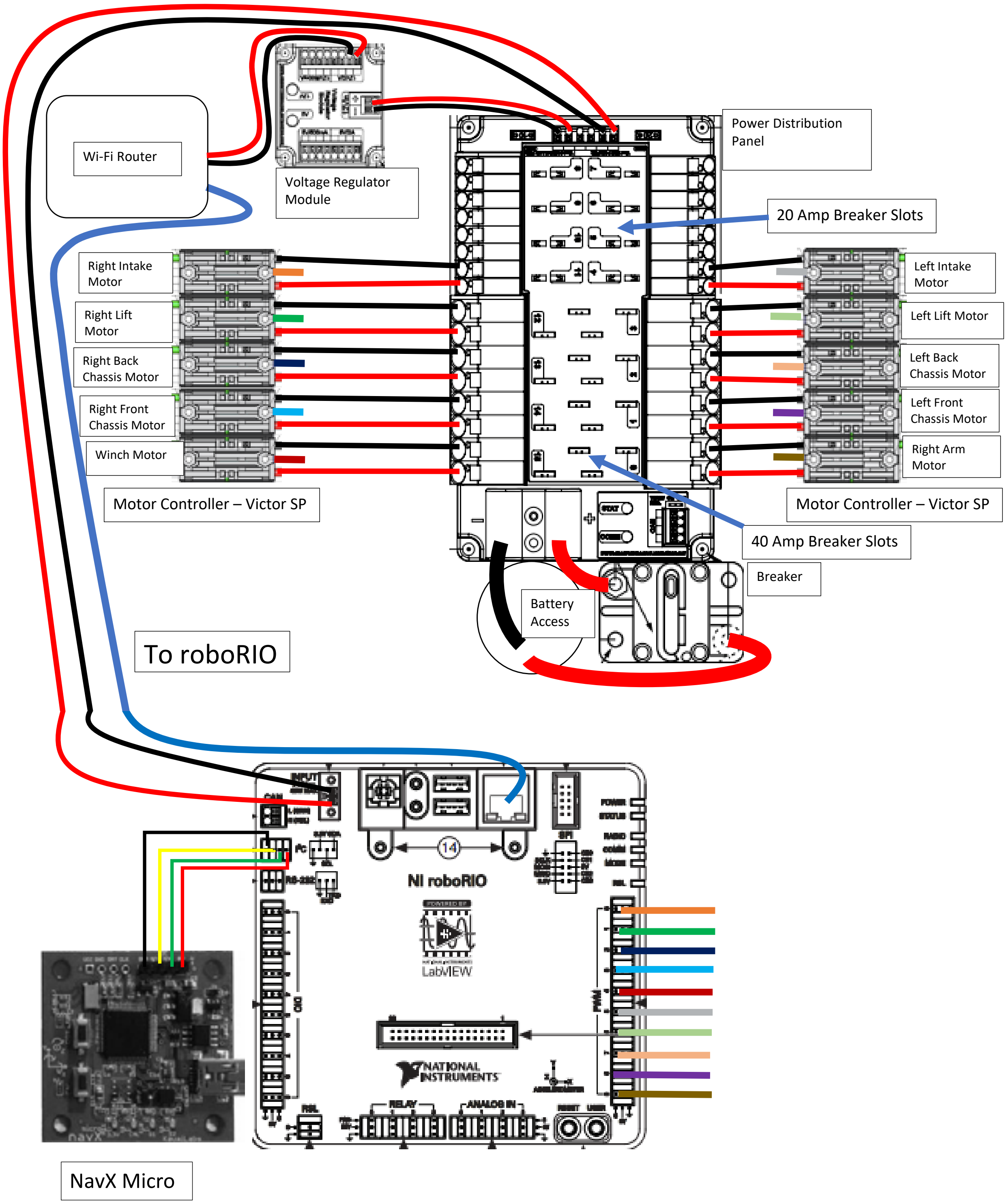
- Standard AndyMark Chassis with 6 wheel drive
- The 6" wheels have a HiGrip Tread for greater traction
- Powered by 2 Toughbox Mini gearboxes 10.71:1 with 4 CIM motors
- Centralised gearboxes, connected directly to the centre wheel
- 755 mm Gates HTD-timing belts transmit motion from the centre wheel to the front and back wheel, 2 each
- At any given point of time only 4 wheels touch the ground enhancing the turning performance by reducing the friction
- An end plate with slots is connect midway to provide structural strength
- The cross members offer a very rigid support to the frame preventing the bending of chassis plates
- The bracing of the inner and outer plates ensures that there is minimal lateral play thereby giving better traction control feedback to the drivers
- The Chassis is " " shaped with a wide central opening to assist the cube collection
- The battery holder is constructed at almost the centre of the Chassis to ensure it is in line with the centre of mass thereby avoiding instability at high speeds and while driving over the hurdles
- The Bane Bot Gearbox with the CIM for winching / scaling weighs well over 5 lbs. This too is placed very low on the Chassis avoid instability at high speeds and over the hurdles
- All the mechanisms are mounted on the rigid Chassis frame using mounting brackets and bearing blocks
- The frame of the Robot is a rigid box type of structure made from the aluminium extrusions
- The electrical circuit board is mounted on a polycarbonate plate secured within the extrusion box structure

Mechanical Construction.

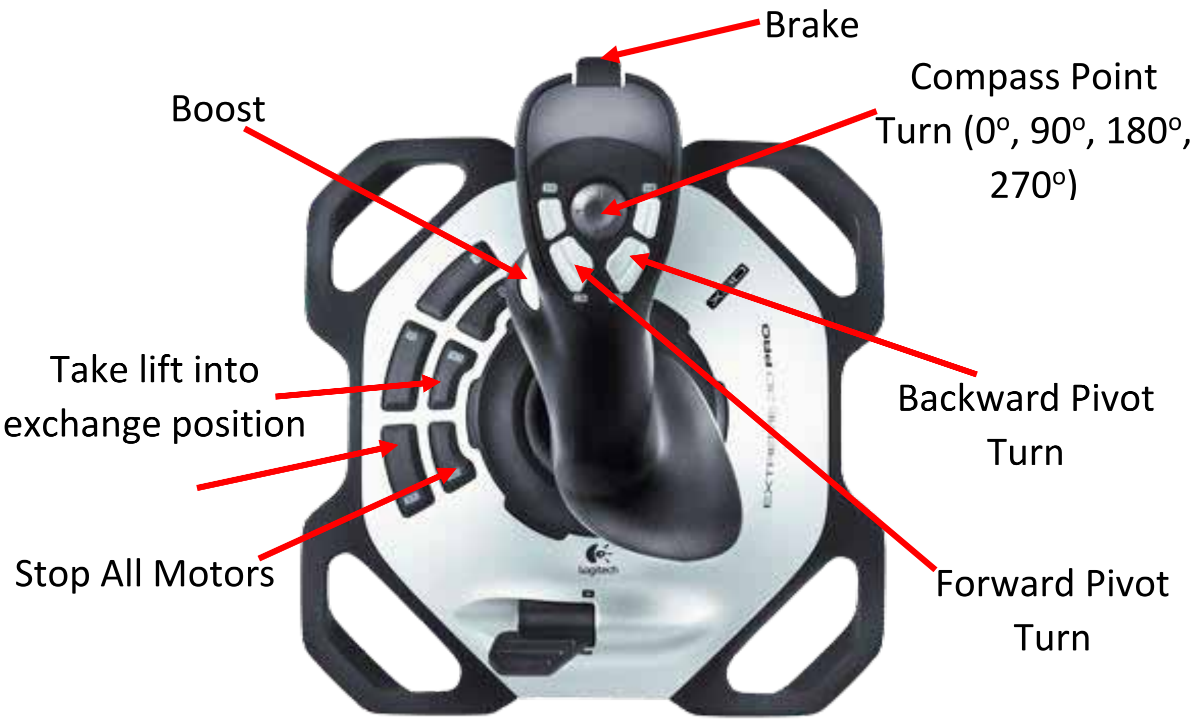




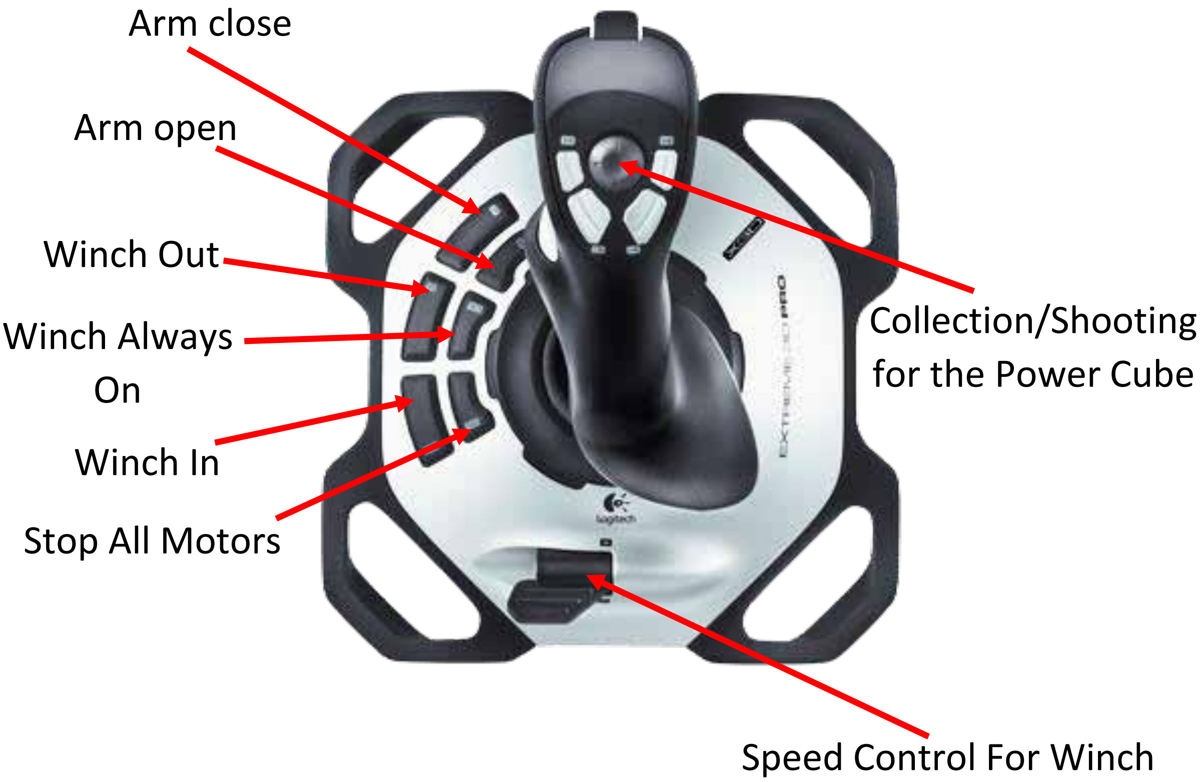
Electrical & Control System.



Joystick Mapping.



Driver 1



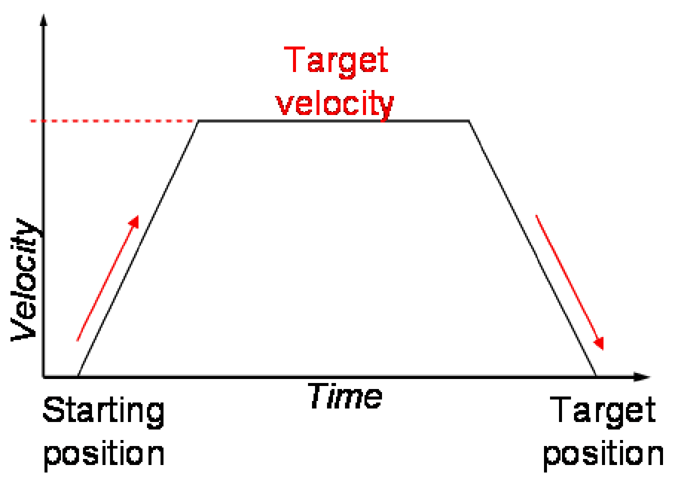
Driver 2

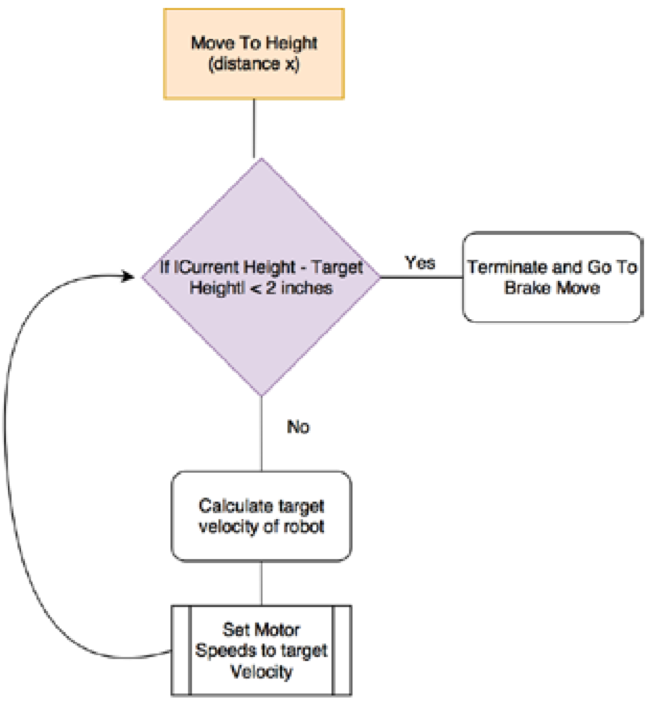
Programming.

- To ensure that robot travels straight in TeleOp and Autonomous we have used Encoders and a Compass Sensor on the robot.
- With the use of PID (Proportional, Integral and Derivative) by using relative angle to the destination as the error magnitude we have successfully made our robot travel straight. Our testing has shown that robot travels straight with ±1° of error.
- Considered and tried alternatives such as trying to synchronize the speed of the left and right side of the chassis, however, we realized that our earlier method gave much better and consistent results.

```
public double movePID(double speed, double initialAngle, double curError) {
    speed *= -1;
    double curAngle = Sensors.navx.getFusedHeading();
    double angDiff = Sensors.findHeading(initialAngle, curAngle);
    double pidMult = Math.pow(angDiff/35.00 + curError/35.00 + 1, Math.signum(-speed));
    double leftSpeed = speed*pidMult;
    double rightSpeed = speed/pidMult;
    move(leftSpeed, rightSpeed);
    return curError + angDiff*0.05;
}
```

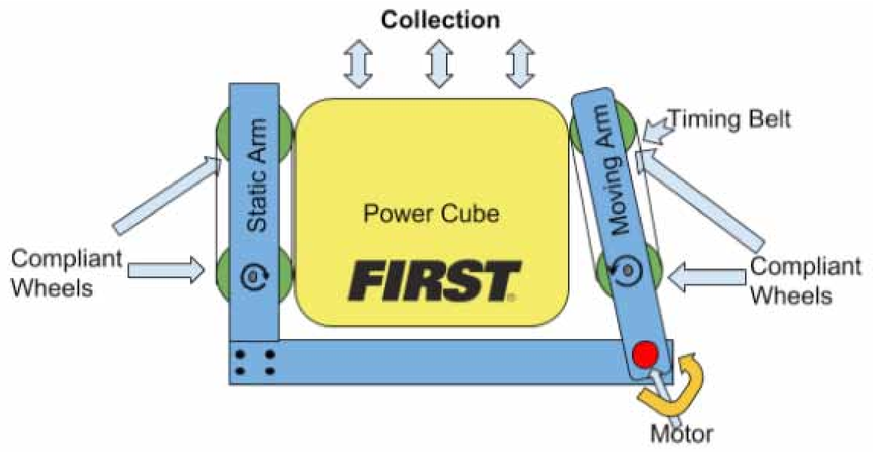
- In Autonomous mode, our goal was to make some fundamental functions which would allow us to abstract our robot movement and make it easier to customize the movement fast in the heat of the competition. We abstracted this by making 2 functions, go Forward (distance, min Speed, max Speed) and turn (destination angle).
- The biggest contributor of error in the our first iteration of the function was that the robot would jerk while starting and ending its routine. To significantly reduce this systematic error we initially accelerate the robot to its max speed and then slow it back down gradually until it comes to rest.
- Target Velocity is any value between -1 and 1. Target Position is the distance the robot has to travel in inches.

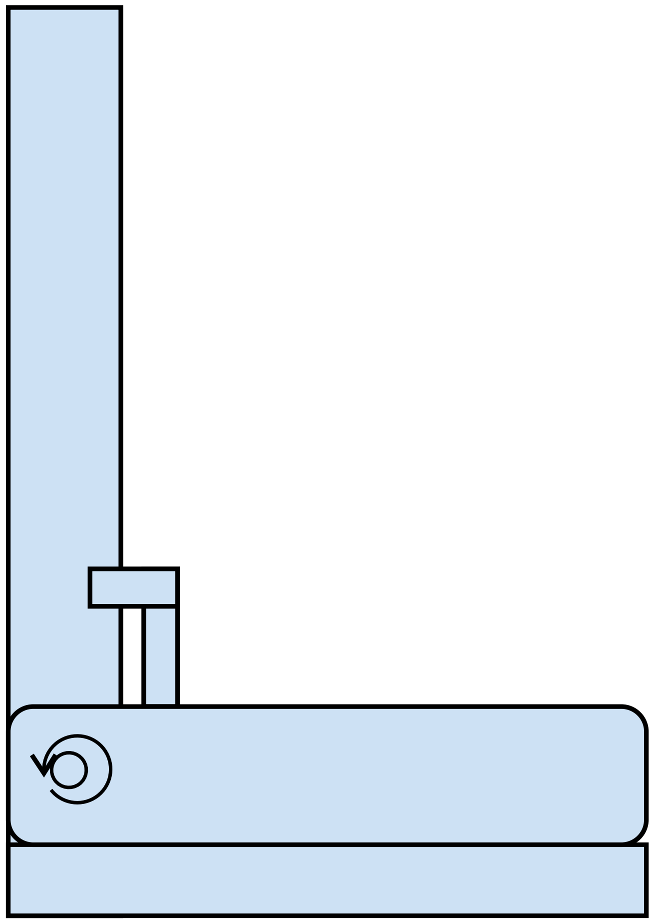




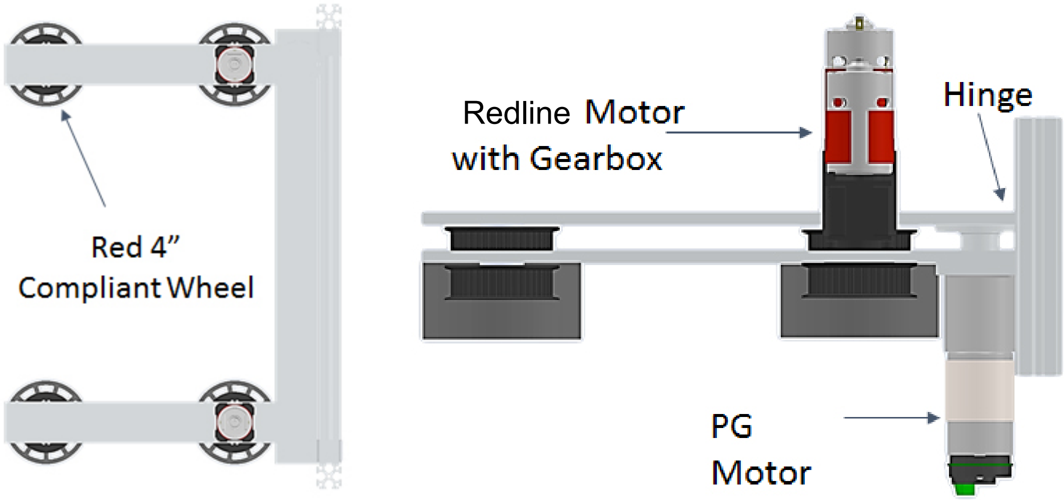
Construction & Working:

- The collector consists of 2 arms, one static, the other a movable arm
- The hinged arm is connected at one end to a Planetary Gearbox Motor
- The movable arm has freedom of motion along the plane of the ground
- We have used 4, 4" Red compliant Wheels, to grip and take in the cube securely and firmly
- All 4 compliant wheels are powered by 2 Red Line Motors, one motor attached on each arm, the power is transmitted to the front wheels using a 555mm timing belt and a 2.5 inch pulley
- The redline motors are geared down to increase the torque output using a BaneBot 4:1 gearbox
- The compliant wheels along with the moving arm, can collect the cube from any position and any orientation (the wheels move in the inward direction to collect the cube)
- We have hinged the entire arm on the 2nd stage of the lifting mechanism so that it can fold inwards with the initial cube at the start of the match
- There is a stopper for the arm that keeps the arm folded inwards at the start. When the arm opens up, it is released from the stopper and falls down along with the cube right in front of the robot
- The cube is firmly secured in the arm, by keeping the PG Motor continuously moving inwards so that all 4 compliant wheels are touching the cube
- For shooting the cube outside, we move the compliant wheels in the opposite direction and also moving the PG Motor inside, which allows us to shot out the cube efficiently and effectively

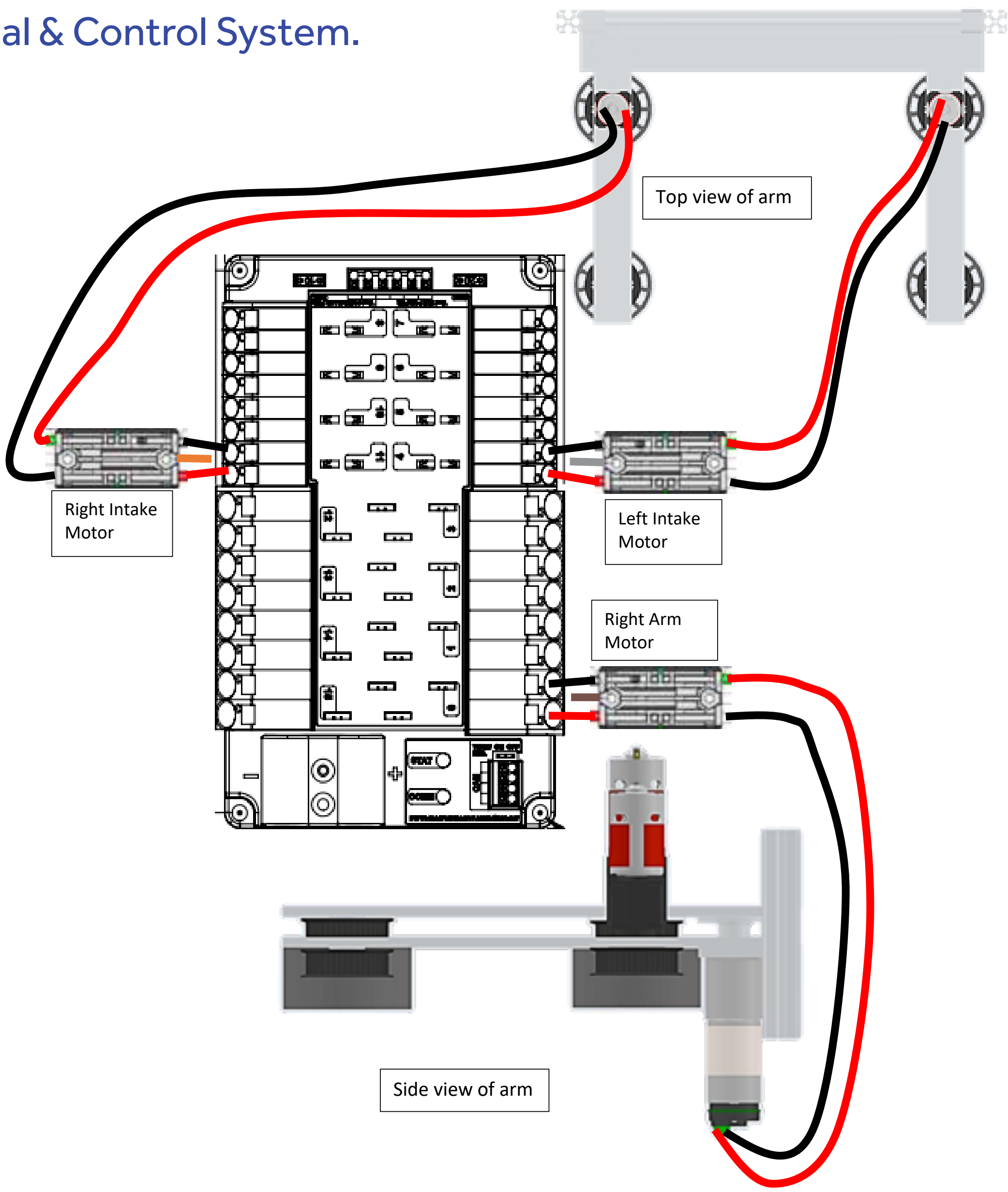




Mechanical Construction.



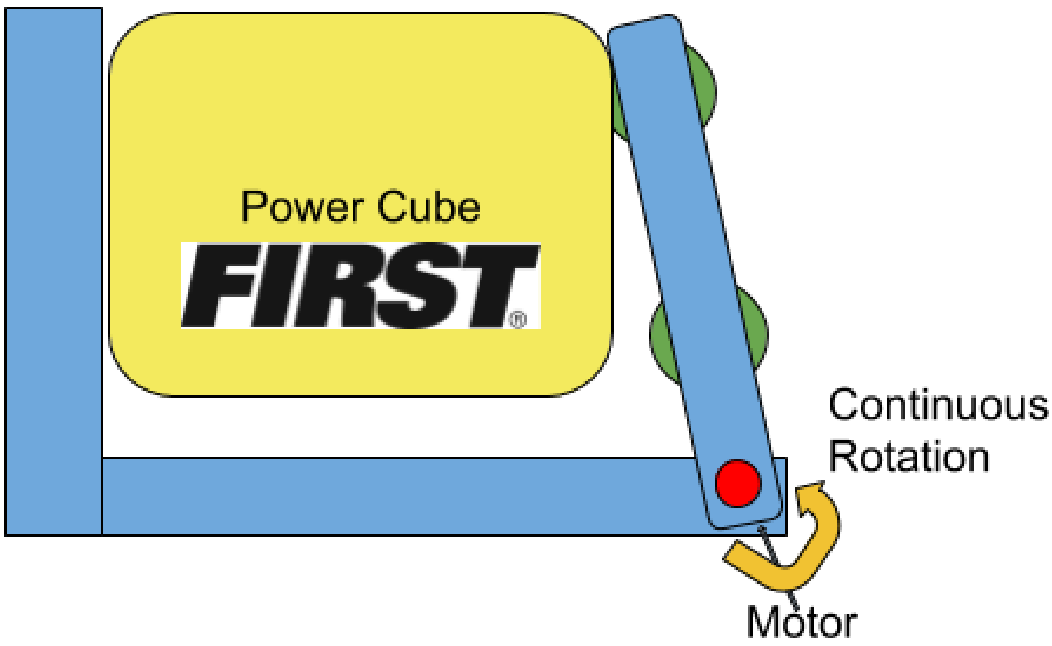
Electrical & Control System.



Programming Techniques.

In the game the powercube can come in the arm at any angle (however most of the times it becomes straight) and because of that the arm doesn't get a good grip on the block. Hence, we assigned an analog stick on the joystick that will rotate the wheels in different directions and make it straight.

Also when carrying the block the arm motor has to constantly press against the block to ensure that it doesn't fall down. To do this we made the default command of the robot to be pressing inside.



Construction & Working:

- We have constructed a 2 stage elevator raise the cube at different levels from carpet to the highest position of 7'6"
- The 2 stage elevator consists of 2 rectangular frames made of 30mm x 30mm Aluminum Extrusion sections
- One frame is stationery while the other one slides over it along the vertical axis
- The "L" shaped hardware fitting is used innovatively as a slider to slide within the groove of the aluminum extrusion
- These sliders are fixed on to the moving frame and they help the moving slide to slide over the stationery / fixed frame
- A similar "H" frame assemble is mounted with sliders to slide over the moving frame
- Thus, the elevator assembly consists of one stationery frame, one moving frame and one "H" frame. These two moving frames make up the 2 stages of the elevator which can rise to a height of 7'6"
- The collector arm is mounted using a hinge on to the "H" frame
- Triangular reinforcement plates are fixed at the corners of the frame to provide stability
- Two planetary gearmotors are used to actuate the elevator mechanism. No load free speed is 75 rpm and stall torque is 16.6 ft-lbs. Encoders are mounted on the motor for better speed control
- Each gearmotor is mounted on a bracket. The gearmotor hex shaft is then connected to a wooden drum by a motor hub
- 2 Pulleys with flat grooves are mounted the top of stationery and moving frame
- A wide 5mm wide high grip flat belt is used to lift Stage I and a 3 mm high grip flat belt is used to lift the arm at Stage II
- 126" of 3mm flat belt, 63" on each side, Green belt
- 182" of 5mm flat belt, 91" on each side, Red belt
- The length of the extrusions is 48"
- The amount of torque and speed to reduce time
- length of extrusions to reach 90 inches

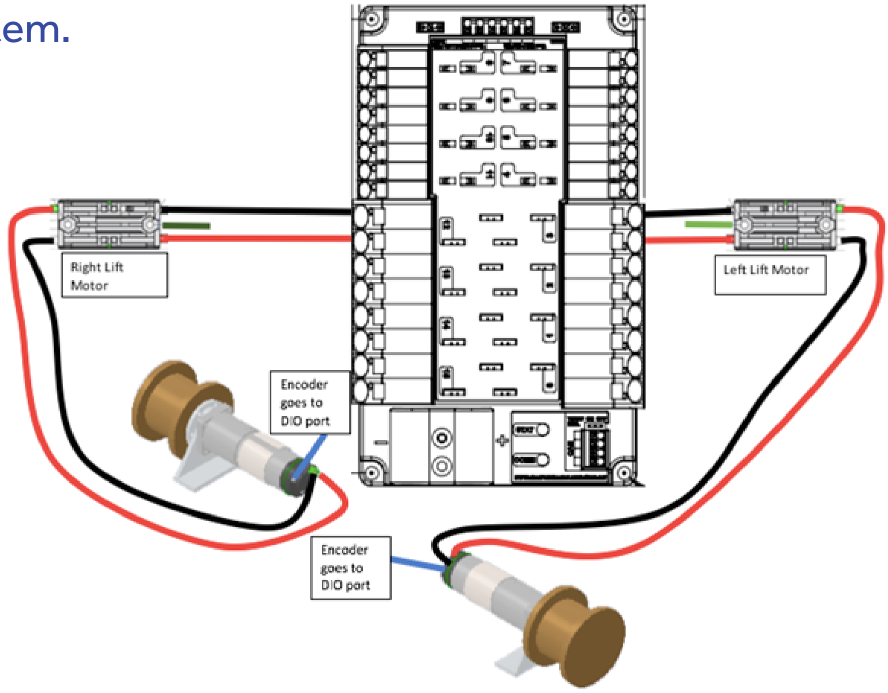
Mechanical Construction.

Electrical & Control System.

To move the lift mechanism up and down, we have two independent motors running.

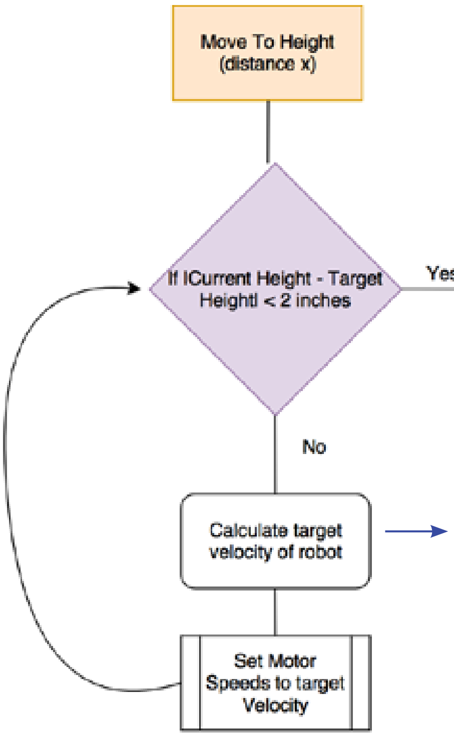
We Synchronize the angular speed of the motor so that the lift is always parallel w.r.t the ground. We have synchronized this using the feedback from encoders in both the motors which feeds the program the rate of moving and we appropriately multiply one of the sides by the ratio of the speeds.

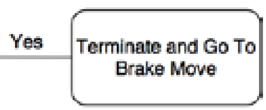
To abstract this subsystem in the code we made a function called Move To Position which takes in a parameter of the height from the bottom of the robot. With the combination of some encoder feedback and math the flowchart shown below describes the function.



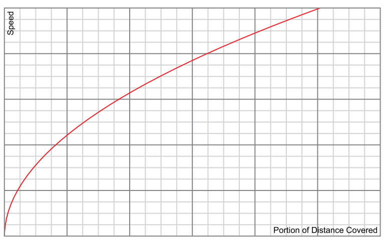

```
public int leftCount, rightCount;
public void brake() {
     left.set((Sensors.leftLE.get() - leftCount)/100.00);
     right.set((Sensors.rightLE.get() - rightCount)/100.00);
}
```

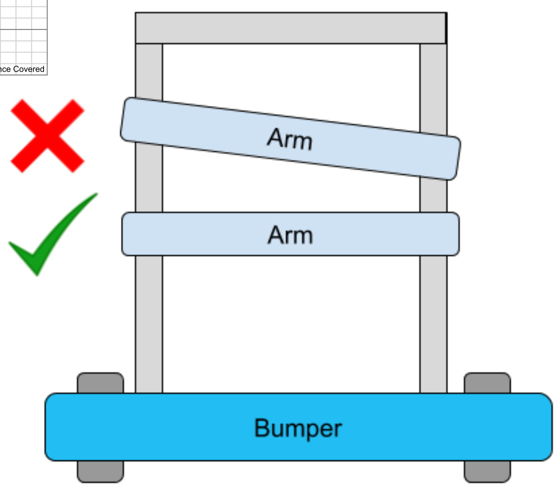
The motor isn't able to hold the lift at an upright position when we are setting it to 0 speed. To rectify this and make sure that the lift position doesn't change because of gravity we are setting the motors to a speed that will bring it closer to the position we want it to be.





The target velocity is not kept constant to make sure that the lift doesn't suddenly jerk. Many different functions can be used. For our robot we used a power function: $y = x^{1/3}$

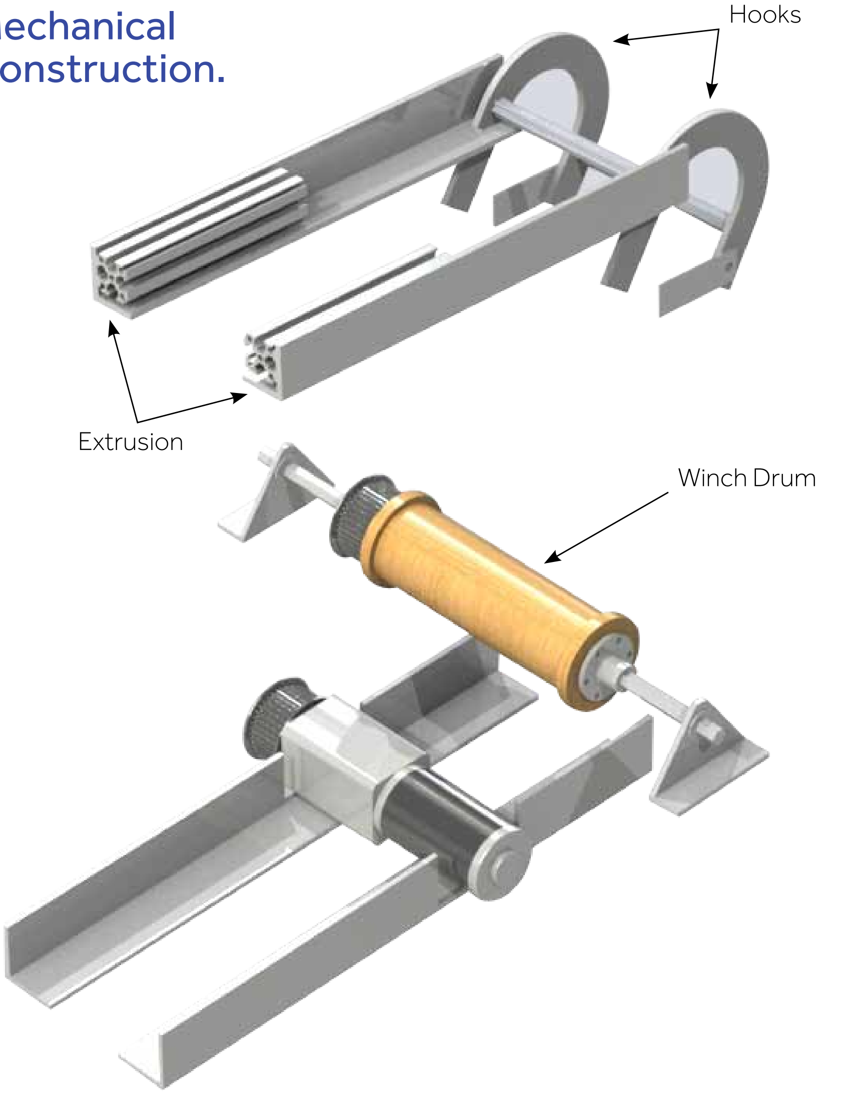




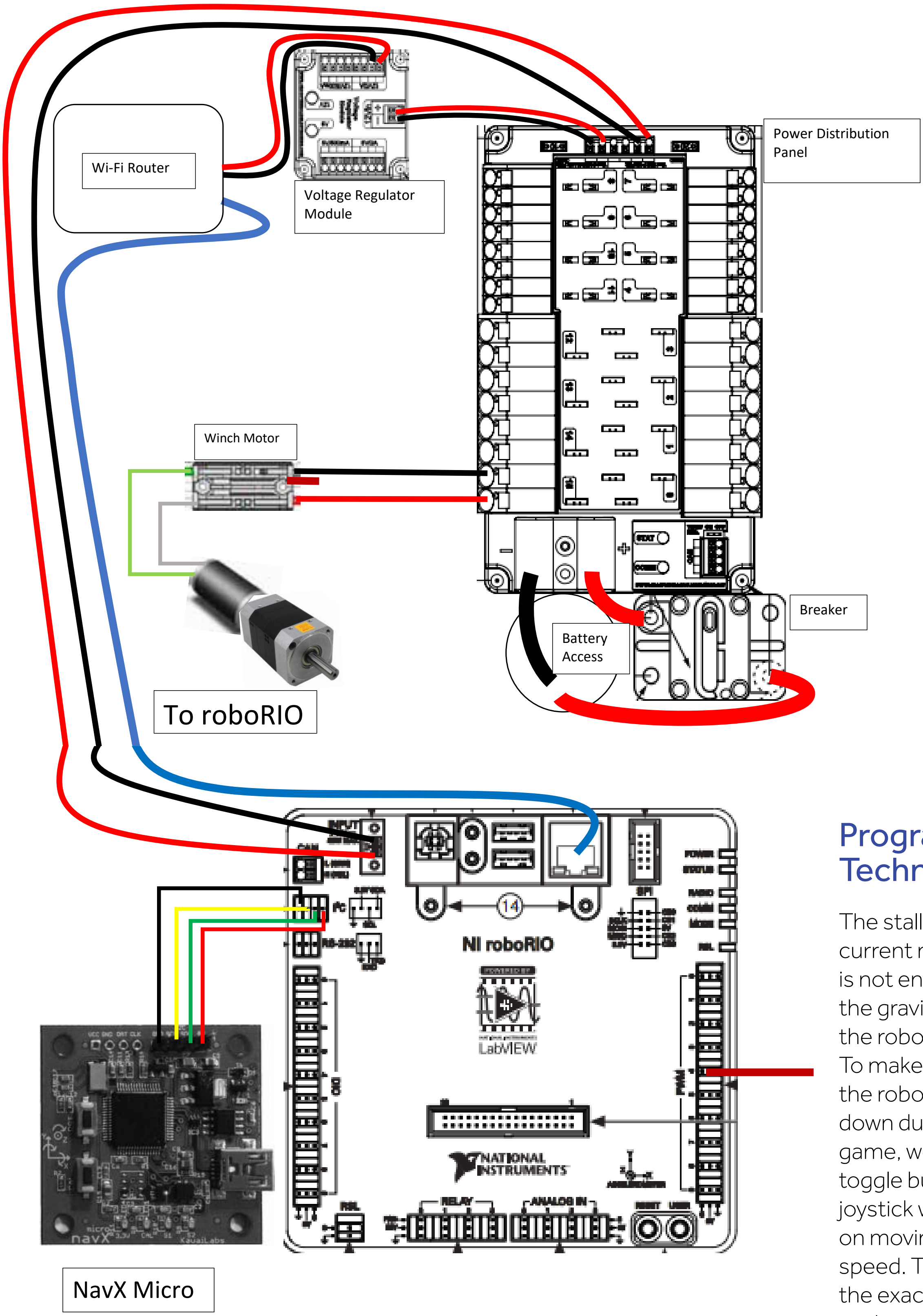
Construction & Working:

- The scaling mechanism consists of a high reduction planetary geared motor connected to a wooden winch roller with 2 timing belts
- The above gear box has a reduction of 64:1 and maximum recommended torque is 85 ft-lb
- The gearbox is very well fixed on to the Chassis by means of the mounting hardware. A cross member is fixed above the gearbox to ensure that it doesn't become loose under heavy loads
- A 2.50" dia x 8" long wooden winch drum is constructed with 2 aluminium flanges of 4.5" diameter mounted on it at the two ends to prevent the rope falling off the drum when they are slack
- A ½" hexagonal shaft x 21" long passes through the centre of the drum along its' entire length
- The hexagonal shaft passes through 2 hexagonal bearings mounted on bearing blocks – at each end
- A pair of toothed pulley is mounted on the Gearbox shaft and the Winch Roller shaft. Two timing belts are attached over the pair of toothed pulleys
- A unique assembly of delivery hooks which are detachable is mounted on a arm attached to the moving lift frame of the elevator
- The hooks are loosely "kept" in slots of the above arm and move in the vertical direction along with the lift frame
- The hook assembly has a "bell" shape on one end allowing easy entry for the "rung" of the tower. All edges are completely rounded to facilitate easy entry of the rung
- A cotton coated 8 mm rope s used to climb / scale on the Tower
- One end of the rope is securely fitted on to the wooden drum of the winch. The rope passes through the hook assembly. The other end of the rope is attached to the extrusion frame of the robot on the opposite side of the winch roller
- The elevator frame lifts the hook arm. The hook assembly is delivered on to the rung and the frame retracts back. Simultaneously, the winch drum / geared motor starts rotating there by lifting the Robot. The two ends of the rope and the part of the rope over the hook assembly forms a triangle
- The weight distribution is very even and the whole Robot is lifted up vertically without tilting
- The and hook arm is at the length of 19"
- The height of the hook is 7"

Mechanical Construction.



Electrical & Control System.



Programming Techniques.

The stall torque in our current motor + gearbox is not enough to fight the gravity force while the robot is in mid air. To make sure that the robot doesn't fall down during the end-game, we have kept a toggle button on the joystick which will keep on moving up at a slow speed. This solution is the exact same solution as the solution for the lift brake mode.

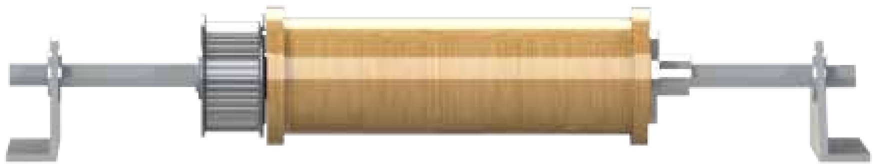
Scaling / Climbing Mechanism

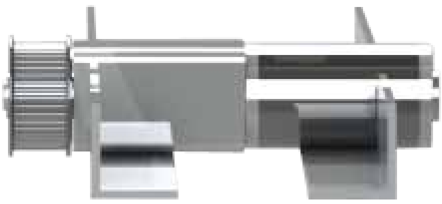
Unique Features.

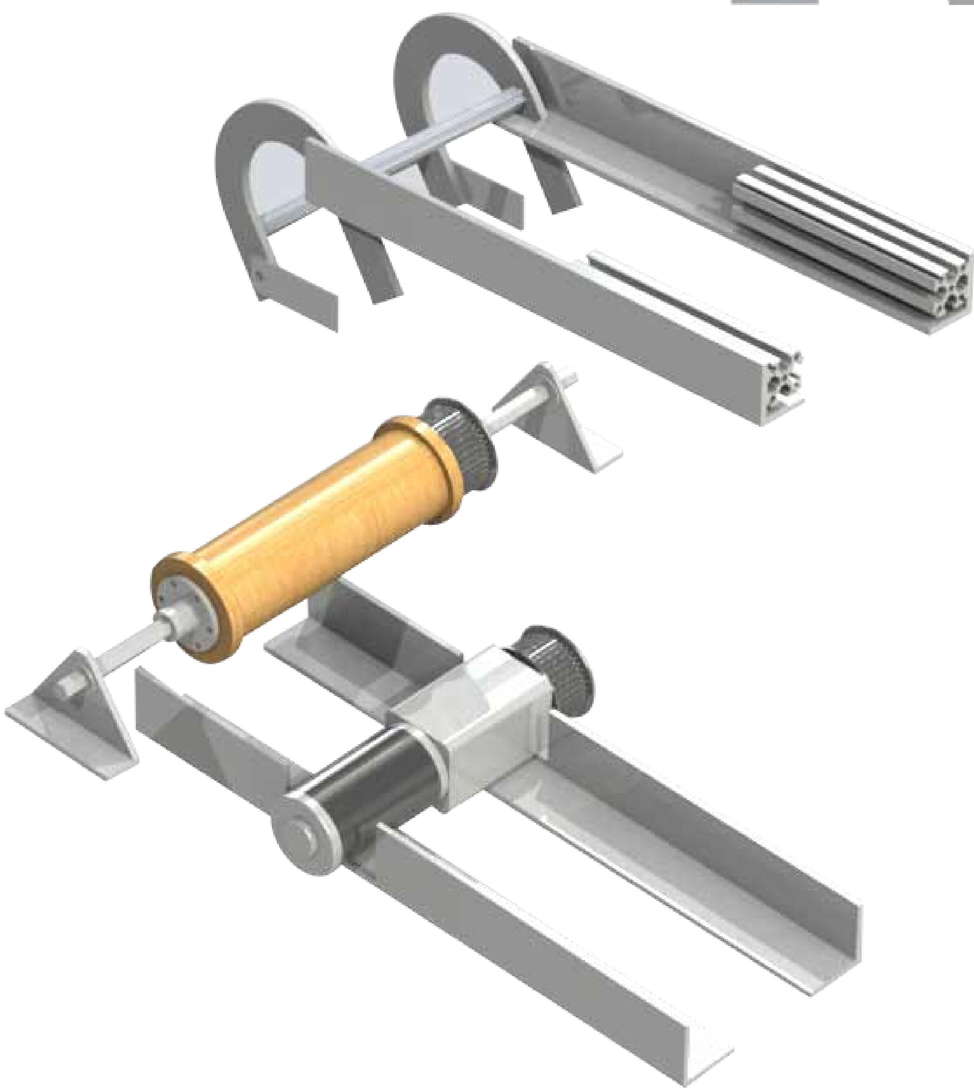
One mechanism (the reach stacker) is being used to actuate another mechanism (the scaling winch)

The hooks are able to detach smoothly without getting stuck and it does not take a lot of time for climbing.

The hooks are built in such a way so that they do not come out after catching the hook and supporting the ropes pull the robot one foot up.







A) Mechanical Structure / Mechanisms

- The collection arm is innovatively used to collect the Power Cubes for any orientation. Since one arm is fixed, this serves as a reference and the other moving arm serves as a "gripper". Just by manoeuvring the Robot, the Power Cube can be easily gripped and collected by the intake wheels
- The "L" shaped right angled fittings were used as "Sliders" so that one frame could slide over the other in the Elevator / Lift Mechanism
- Flat belts with high grip were used to lift the moving frame over the stationery frame. The thin 3mm wide belt moved effectively over the thicker 5mm wide belt for the 2 stage lift without friction
- The Elevator Mechanism was effectively used to deliver the hook assembly over the rung
- The triangular vertices of the Winch Roller, Hook Assembly and Robot Frame offer complete stability and balance during scaling / climbing thereby reducing the effort required by the gear box

B) Electrical & Control System:

- All the mechanisms are connected to the motors and all connections are done using "Power Poles". This makes the whole system very versatile and modular
- Optimised joystick experience for drivers using combination buttons like a video game "Power Up"
- Use Raspberry Pi to stream multiple cameras

C) Programming:

- Made a robust code to work in all situations
- Used PID using NAVx sensor
- Reduced jerk on the robot using "Smart Motion Profiling"
- Varied speed of left and right intake wheels to grab Power Cubes from versatile angles
- Used encoders to avoid overshooting and adding extra stress

Mass / Torque Calculation for Geared Motors.

For the Elevator Mechanism:

Stall Torque = Radius *Force

$$\tau = mg$$

Where:

τ_s is in newton-metre (N-m)

m is in kilogram (kg)

r is in metre (m)

Stall Torque for the Gearmotor PG-71:

$$\tau_s = 22.37 \text{ Nm}$$

Radius of the drum, r = 35 mm = 0.035 m

$$m = \frac{22.3}{0.035 \times 9.81} = 65\text{kg}$$

For the Climbing / Scaling Mechanism:

Stall Torque, τ_s = mass (m) x g x radius (r)

Where:

τs is in newton-metre (N-m)

m is in kilogram (kg)

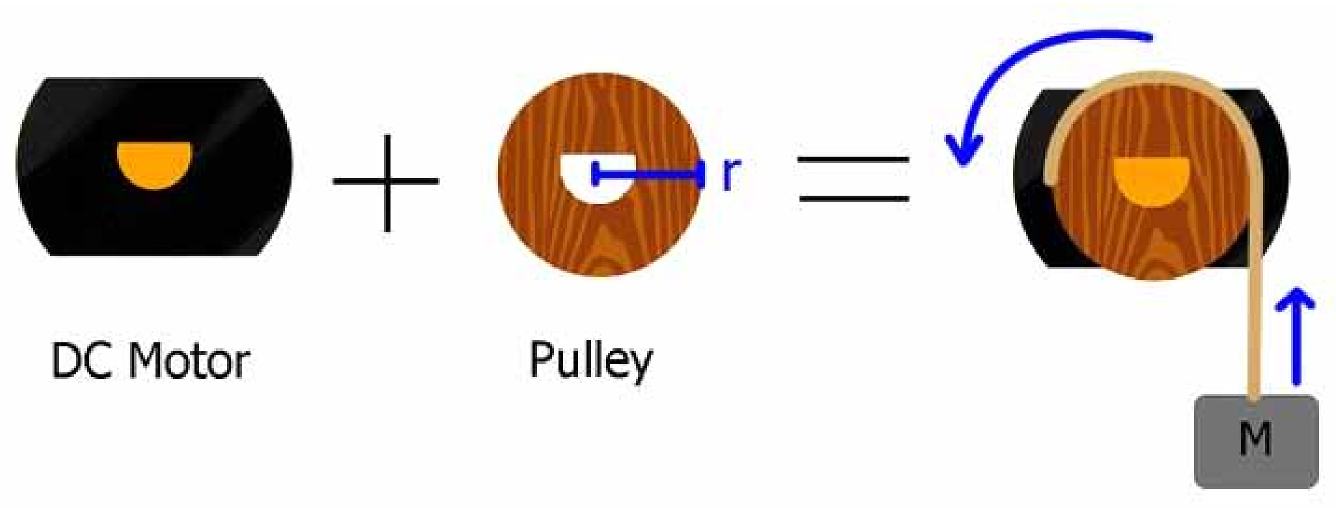
r is in metre (m)

Stall Torque for the Bane Bot Gear Box,
τ_s = 85 ft - lbs = 114.6 N-m

Acceleration due to gravity, g = 9.81 m/s^2

Radius of the drum, r = 55 mm = 0.055

m Mass, m = 114.6 / (0.055 x 9.81) = 212 kg



Analysis of Tension In Flat Belt:

Weight of the Arm + Elevator Assembly = 12.50 kg

The weight the assembly carries = 12.50 x 9.81 = 123 N

Thus, W = 123 N

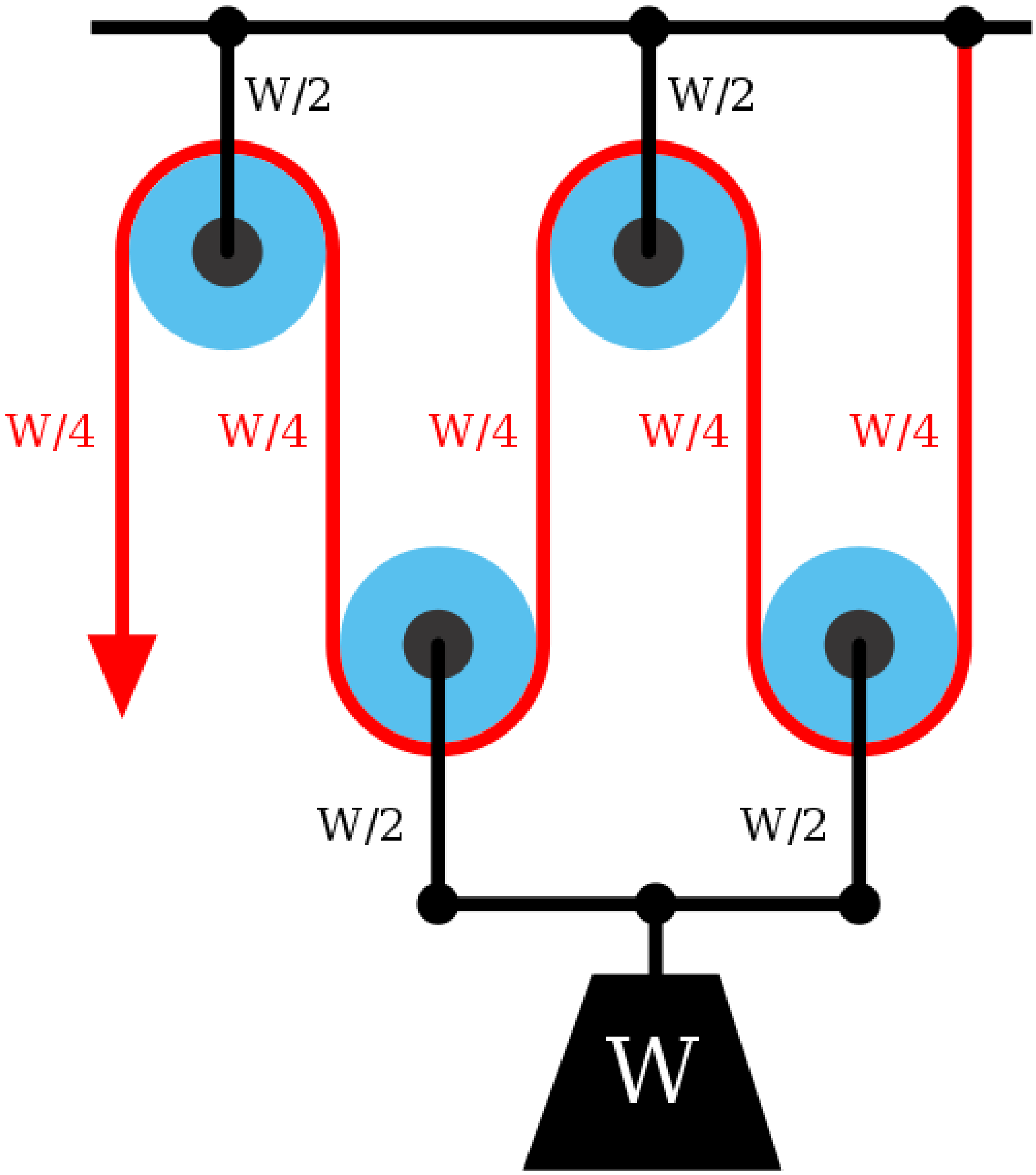
The two bottom hooks are able to carry equal weight of the load W.

Thus, each of the fixed hooks will be subjected to a load of W/2 = 61.50 N

The flat belt sections attached each of the hooks are in turn subjected to a load of W/4 = 30.75 N

The tensile strength of the flat belts is sufficient to carry a load of 300 N in each of it's sections.

Thus, the belt is safe to carry this load



Robot & Engineering Team

Adhyyan Sekhsaria

Aarushi Majumder

Akash Chauhan

Harsh Savla

Hitansh Doshi

Ishaan Thakur

Jai Jariwala

Rahesh Saraf

Riyaan Bakhda

Uchit Shriyan

Vatsin Suchak

FACTOR

FRC TEAM 6024

"When you want to know how things really work, study them when they're coming apart."

(WILLIAM GIBSON)