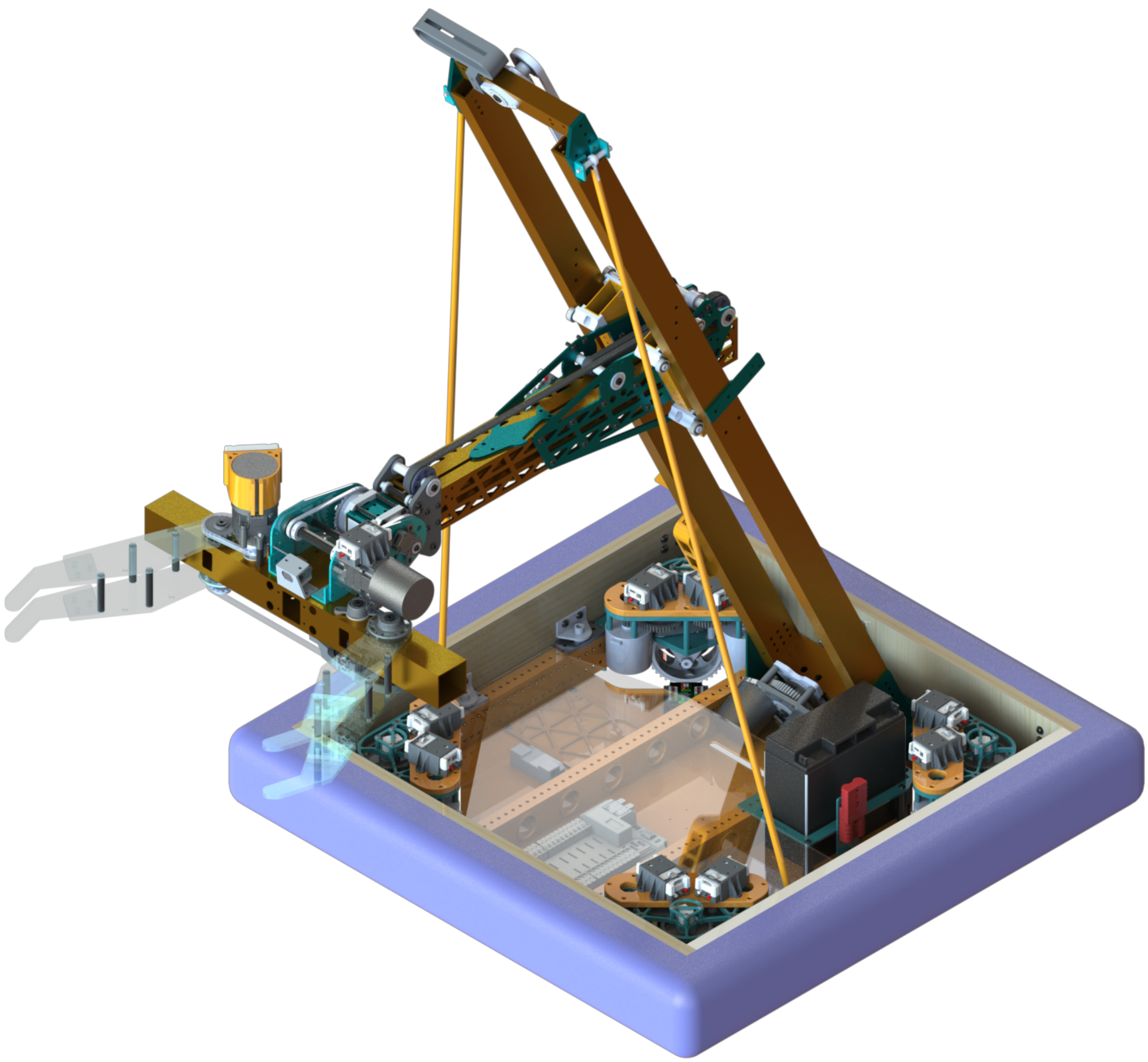
Team 3476: Code Orange

Technical Documentation

Presenting our 2023 Robot:

BAJA



“

I think it is amazing that this team has everything vertically integrated, so they can go from a part designed on the computer, to the manufacturing center, to the powder coating center, to then be assembled on the robot within an hour.

-Andrew Hedge

”

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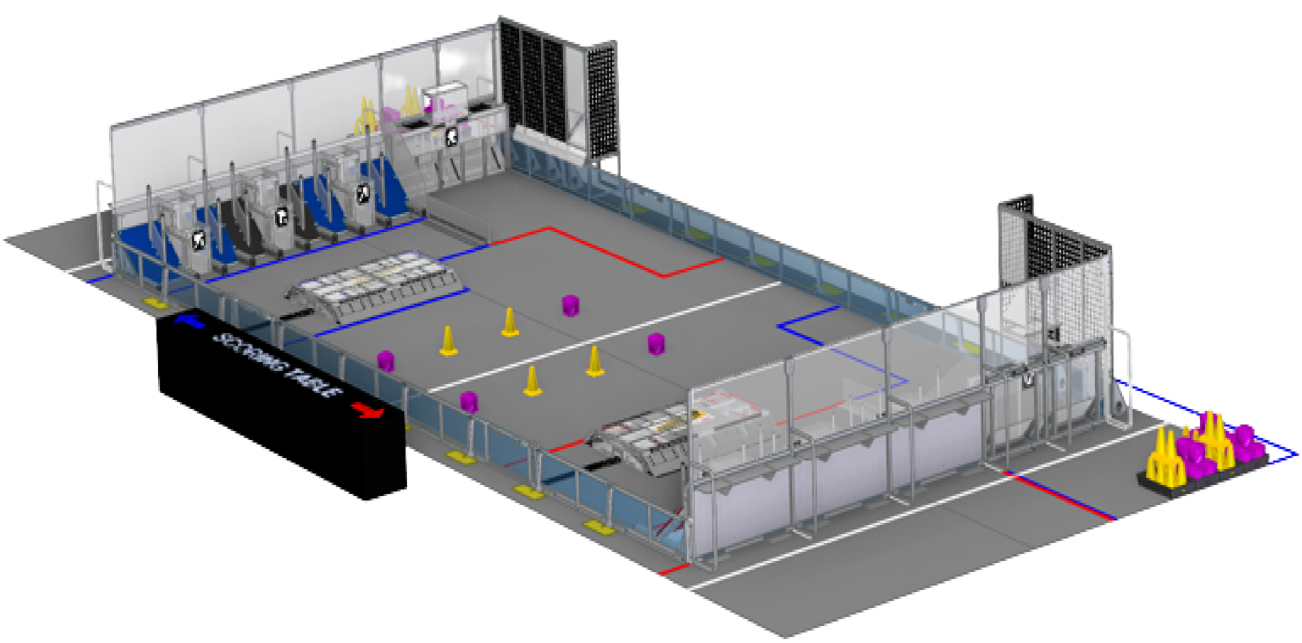
I. Design Process

Design Requirements

Actions:

- Intake game pieces from the ground and from substations
- Place cones and cubes onto their respective nodes
- Score game pieces during auto
- Balance on the charging station with alliance partners for ranking point
- Score links for an extra ranking point



Temporary: Wish, Prefer, Demand List:

Robot Features	W/P/D
Drive every match	Demand
Omnidirectional movement	Demand
Intake cubes from the ground	Demand
Intake cubes against walls	Demand
Intake cubes from the double substation shelf	Demand
Intake cubes from any orientation	Demand
Put cubes on high nodes	Demand
Put cubes on middle nodes	Demand
Put cubes in hybrid zone	Demand
Score cubes in auto	Demand
Moving scored cube to a different level	Prefer
Intake cones right-side up from the ground	Demand
Intake cones sideways from the ground to score in hybrid zones	Demand
Intake cones sideways from the ground to score on poles	Demand
Intake cones from the double substation shelf	Demand
Intake fallen cones from any orientation	Demand
Intake cones against walls	Demand
Be able to orient cones to score	Demand
Put cones in high zone	Demand
Put cones on middle nodes	Demand
Put cones in hybrid zone	Demand
Score cones in auto	Demand
Moving scored cone to a different level	Prefer
Score links	Demand
Get onto charger station while favorable	Demand
Get onto charger station while unfavorable	Wish
Get onto charger station while neutral	Demand
Balance on charging station	Demand
Balance on charging station with 1 other robot	Demand
Balance on charging station with 2 other robots	Demand
Charging station balance in auto	Demand
Self-balancing charging station	Demand
Small frame perimeter	Demand
Dual-use intake	Prefer
Light robot	Prefer
Don't tip	Demand
Fast cycle times	Demand
Accelerate fast	Demand
Stay within 48" extension limit	Demand
Stay within 6' 6" height	Demand
Hold only one game piece	Demand
Have the robot know what item it's holding at all time	Prefer
Pose estimation	Demand
Know what cones are scored	Prefer
Automated alignment	Demand
Manual alignment assistance	Demand
Play defense	Demand
Don't turn during cycles	Prefer
Don't run over game pieces	Demand
Drive over wire harness	Demand
Easy to repair	Demand
Easy to lift	Wish
Easily replaceable battery	Demand
Easily replaceable bumpers	Demand
Ability to communicate which game piece to human player	Demand

Key	
Demand	
Prefer	
Wish	
RPs	
5 links (sustainability bonus) OR 4 links + coopertition bonus - 1	
26 charged station points (activation bonus) - 1	
Win - 2	
Tie - 1	
Points TeleOp	
Top zone - 5	
Middle zone - 3	
Hybrid zone - 2	
Docked and engaged - 10 per robot	
Docked (not engaged) - 6 per robot	
Park in community - 2	
Fouls - 5	
Tech Fouls - 12	
Points Auto	
Top zone - 6	
Middle zone - 4	
Hybrid zone - 3	
Docked and engaged (1 max) - 12	
Docked (not engaged) (1 max) - 8	
Leave community - 3	
Cards	
Red	Yellow
MEAN	Being in the field before you're allowed to
Disable/break other robot(s)	Stepping over field boundaries
Accumulate 2 yellow cards	

Overall Design Considerations

Design requirements:

- Reach the highest scoring locations
- Simple design
- Easy to maintain
- Lightweight
- Easy to operate
- Pick up and score quickly

Designs considered:

- 1 degree of freedom pivoting arm
    - Pros:
        - Simple and light
        - No rotation necessary between scoring and intaking cubes
    - Cons:
        - The length required to score on the top node would not fit within stow configurations
        - Rotation necessary between scoring and intaking cones
- 2 degrees of freedom - elevator with passthrough
    - Pros:
        - No rotation necessary between scoring and intaking cubes
    - Cons:
        - Still does not fit within stow configurations
        - Passthrough adds complexity
        - Rotation necessary between scoring and intaking cones
- 3 degrees of freedom - pass through on elevator, with telescope
    - Pros:
        - Can reach the highest node
        - No rotation necessary between scoring and intaking cubes
    - Cons:
        - Excessive amount of elevator stages required (3)
        - Passthrough seen as an over-optimization
        - Rotation necessary between scoring and intaking cones
- 3 degrees of freedom - elevator with telescope with wrist attached to intake
    - Pros:
        - Wrist allows for adjustments when scoring
    - Cons:
        - Would still require 3 stages of telescope
        - Rotation necessary between scoring and intaking game pieces
- 3 degrees of freedom - slanted elevator with telescope with wrist attached to intake
    - Pros:
        - Would only require a 1 stage telescope
        - Simple and light
    - Cons:
        - Requires the robot to rotate between scoring and intaking

Arm

Design requirements:

- Precise extension
- Able to reach the high nodes
- Extend and retract in less than a second
- Lightweight but durable

Designs considered (telescope):

- Pneumatic Cylinder
    - Pros:
        - Proven design
        - Simple to implement
    - Cons:
        - No medium extension length--only fully extended or fully retracted
        - Requires extra pneumatic pump system
- Lead Screw
    - Pros:
        - Robust
        - Precise positioning
    - Cons:
        - Slow
        - Difficult to repair
        - Heavy
- Constant-Force Spring and Winch
    - Pros:
        - Straight forward controls
    - Cons:
        - Complicated arrangement
        - Difficult to repair and prone to tangling
- Belt Driven
    - Pros:
        - Precise position
        - Relatively easy to repair
        - Lightweight
    - Cons
        - Slightly less durable
        - Difficult to make reparable

Intake

Design requirements:

- Pick up both game pieces
- "Touch it - own it" philosophy
- Not too heavy
  - Prevents robot from tipping
  - Reduces elevator load

Designs considered:

- Two-pronged horizontal claw with rollers
  - Pros:
    - "Touch it - own it"
    - Able to launch game pieces for scoring
    - Large intaking range and centers upright cones for reliable positioning
  - Cons:
    - Can't pick up the cone easily from all knocked down orientations
    - Unable to reorient cone
    - Heavy
- Horizontal claw with grip
  - Pros:
    - Secure grip
    - Can grab both the cone (upright) and cube
    - Much lighter than intake with rollers
  - Cons:
    - Can't "touch it- own it"
    - Can't pick up the cone easily from all knocked down orientations
    - Unable to reorient cone

Drivebase

Design requirements:

- Quickly move the robot across the field
- Precise robot movements

Designs considered:

- Swerve Drive
    - Pros:
        - Movement in many directions
        - Can turn while translating
        - Individual wheel control (for resistance to light pushes and slanted terrain)
    - Cons:
        - Use of many motors
        - Heavier and more complicated compared to West Coast Drive

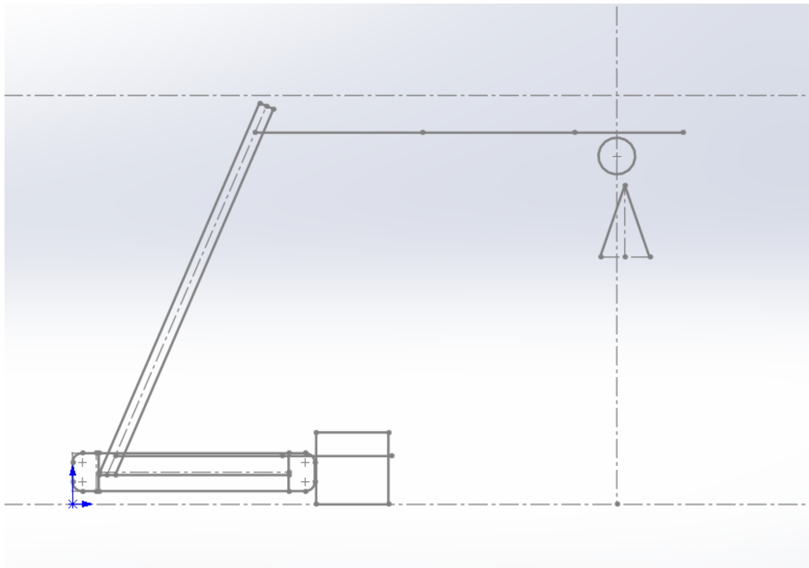
- Small Robot
    - Pros:
        - Less weight
        - Quicker acceleration
        - Easier to maneuver on the charge station
    - Cons:
        - Pushed more easily under defense
        - Less space for mechanisms
- Bumpers
    - Higher from the ground to minimize collision with the charge station

Prototyping

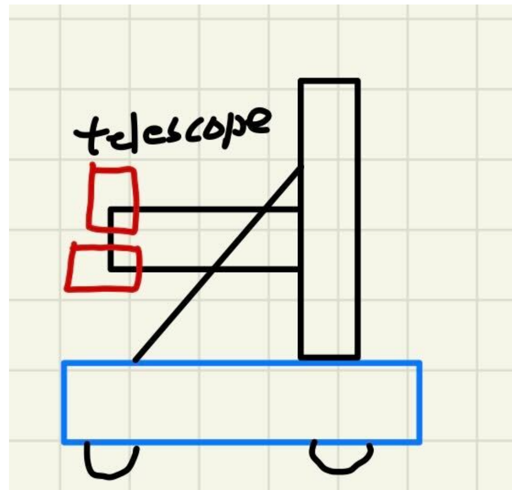
Next, our team splits into smaller subsystem groups to prototype ideas following our wish, prefer, demand list. These teams are composed of experienced and new students to promote passing down knowledge.

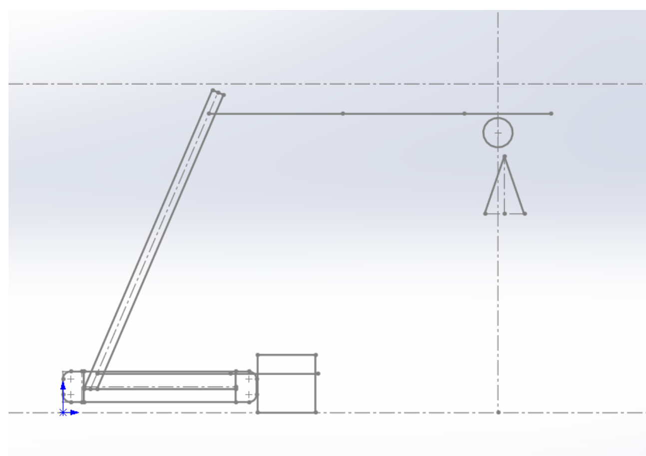
Subsystem groups brainstorm ideas and build prototypes with wood and scrap materials. It is important to collect **data** and document **functionality** through video in this step so designers can look back to determine subsystem specifications.

Elevator



Arm





Intake

CAD

Upon finishing prototyping we move on to the next step, CAD. We select our most successful prototypes of each mechanism and CADers begin the process of designing. Many meetings and open discussions take place to facilitate coordination between mechanisms. CADers adapt their designs based on constant feedback and new ideas. They then present their ideas to team members and mentors for approval.

After a design is approved, parts need to be made by machinists. Drawings are made for each part of the design so that machinists can fabricate the parts. The drawing is a 2D diagram with material specifications and dimensions so the part can be accurately machined.

New ideas and iterations are found throughout the season, so changes need to be implemented. CADders must quickly design and enact these changes so that the robot will be ready for competition. The CAD team is one of the most important divisions of our team because it results in a cohesive design that can be manufactured and assembled fluently.

Fabrication

The manufacturing sub team has the most people on our team and works to bring the robot model, which is designed by the CADders, into reality.

With hundreds of parts to be manufactured, **organization** and **quality** is key. The manufacturing lead ensures each part is made to the tolerance specified on the drawing and completed parts are properly labeled for powder coating and assembly.

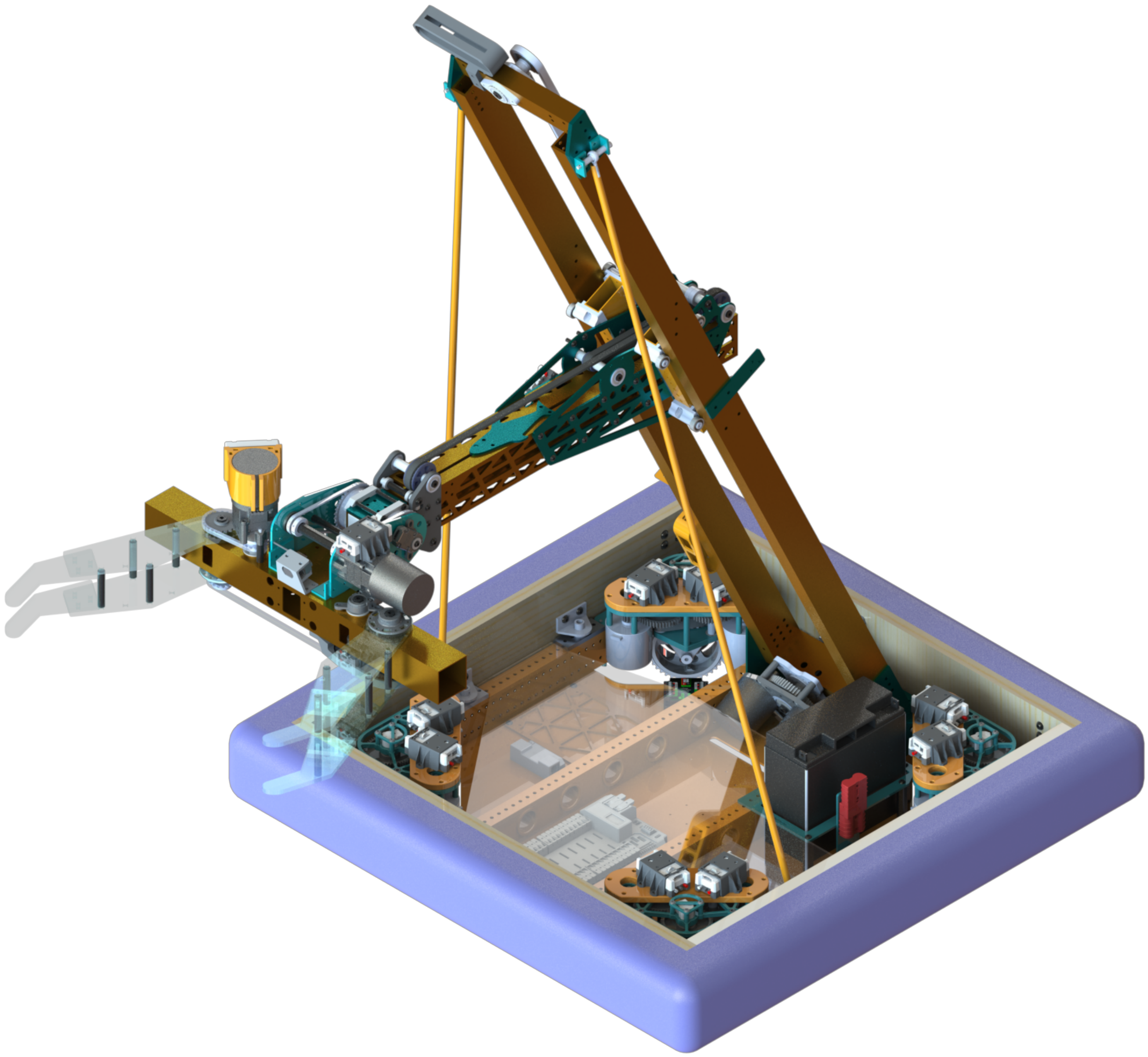
Our team uses **basic machinery** like the bandsaw, the chop saw, the bench grinder, and the belt sander as well as **advanced machinery** such as the mill, the lathe, the laser cutter, the CNC mill, and the CNC router to manufacture our robot.

Unique parts like camera mounts or custom pulleys can be created using our Ender, and Markforged 3D printers. The Markforged printer allows us to print with a carbon-fiber/nylon filament for load-bearing parts.

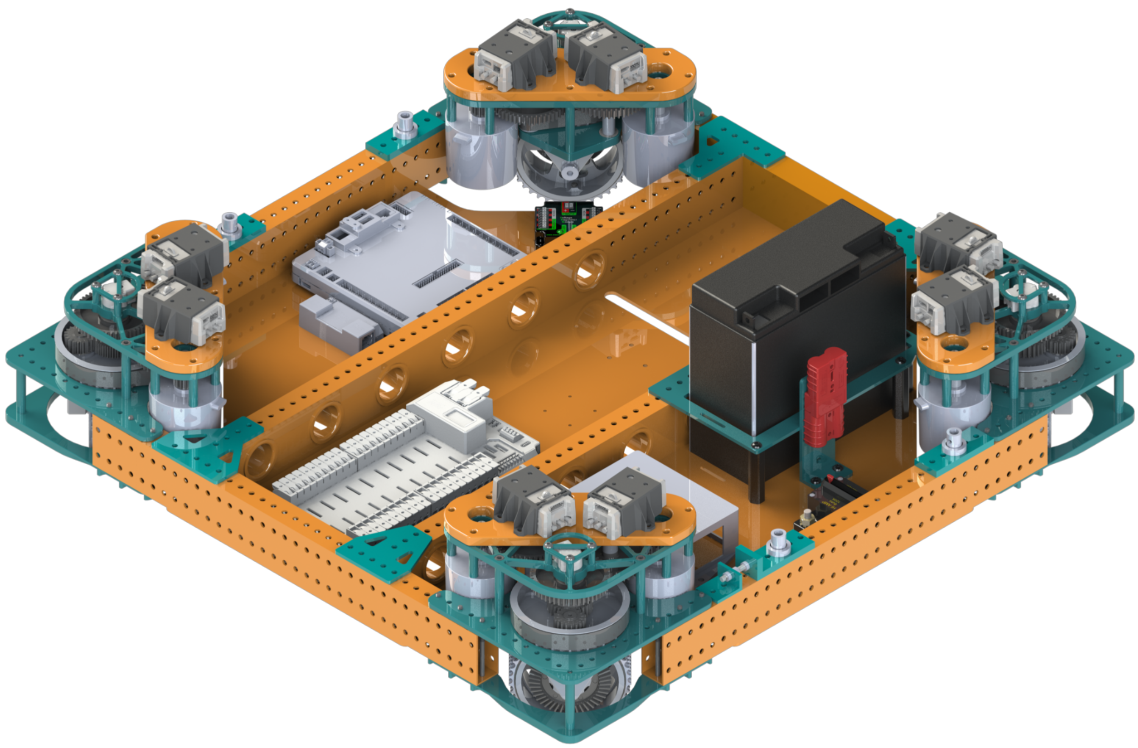
II. Mechanical Design

Final Design

Dimensions: 26in x 26in x 53.6in, ~97 pounds



Drivebase

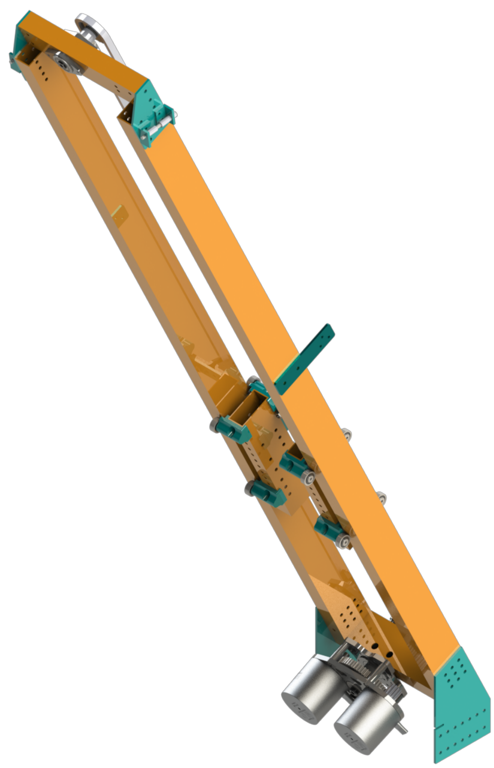


- **Frame**
  - 26in X 26in
  - 1/16in box tubing drive frame
  - 1/8in box tubing cross rails for elevator mounting along with a solid steel bar behind the elevator to help with lowering the center of gravity

- **Swerve Drive**
  - Four SDS MK4i L2 swerve modules driven by 8 Neos
  - 4in traction wheels

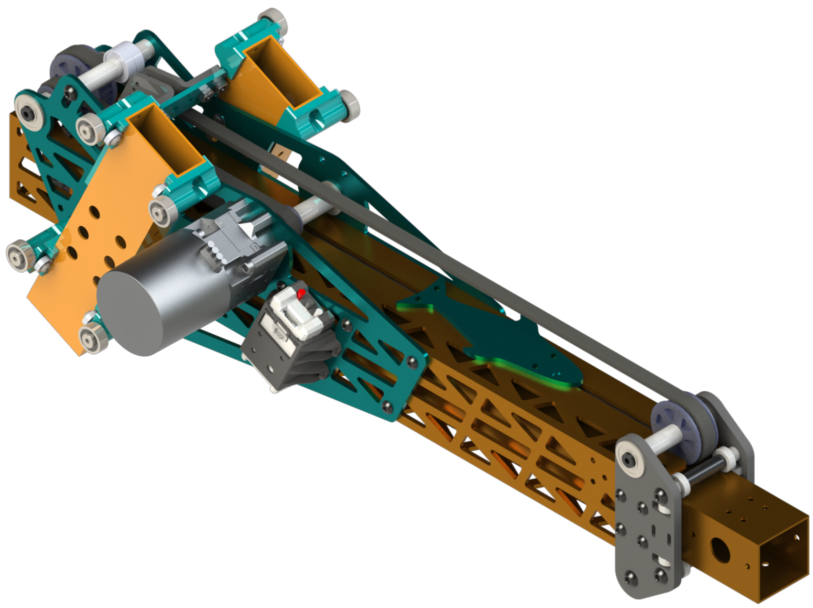
- **Electronics Mounting**
  - RoboRIO, motor controllers, an ethernet system, and PDH are mounted on the topside of the belly pan.

Elevator



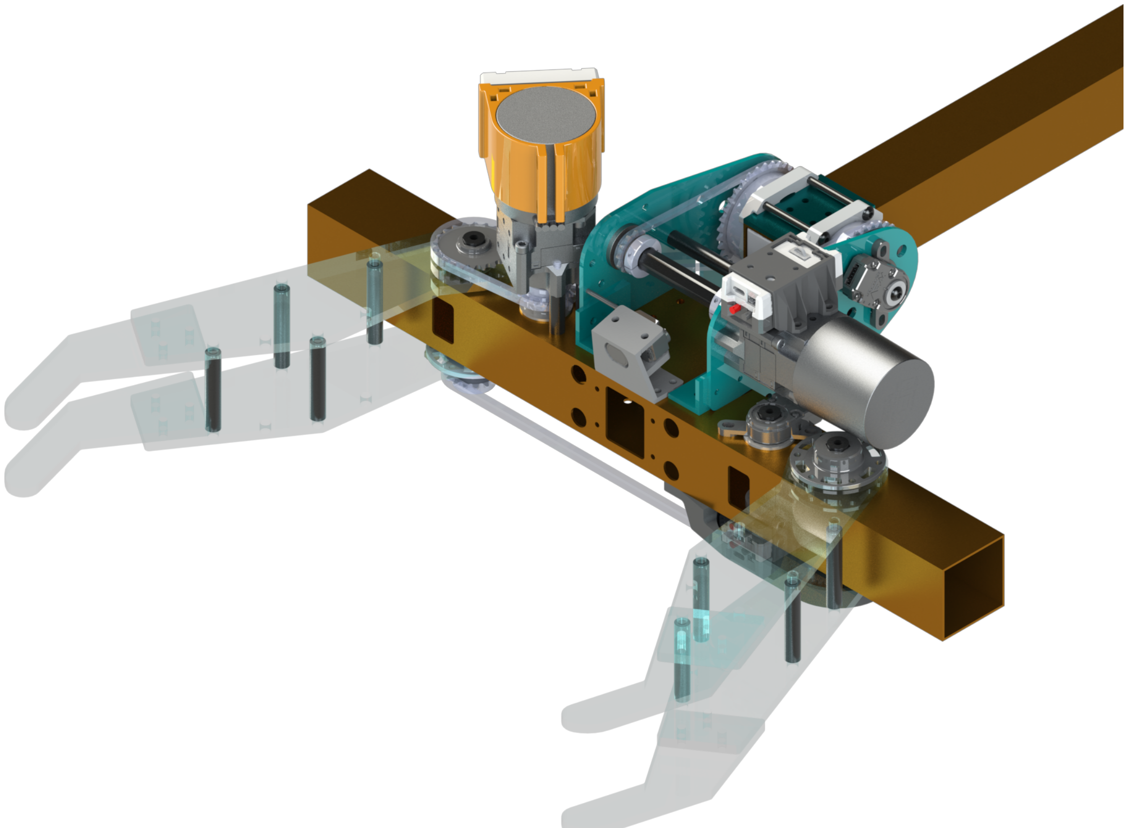
- **Elevator**
  - Single stage elevator with chain that travels 42in in less than a second
  - #25 Chain Drive
  - Angled to maximize reach outside of frame perimeter
  - GreyT Elevator bearing blocks and gearbox
- **Gearbox**
  - Driven by two NEOs at a 5:1 ratio

Arm



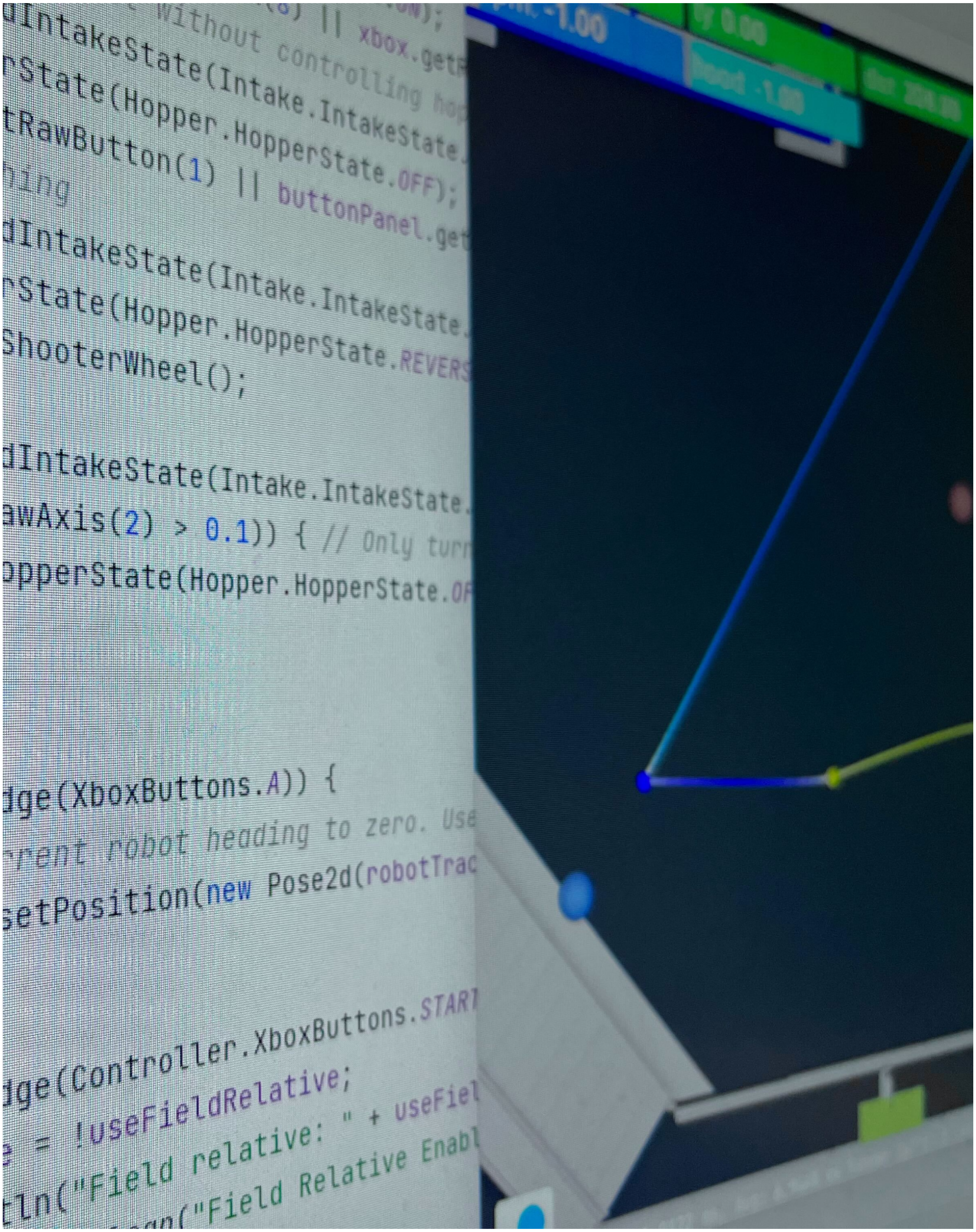
- **Telescope**
  - 3D printed bearing blocks on the bottom of the inner tube and at the top of the base tube for rigid and smooth extension
- **Belted System**
  - Pulley system is driven by one NEO with a 4:1 MaxPlanetary gearbox
  - Extension and retraction in ~0.75s
  - A 3D printed plate with matching tooth profile clamps the belt to the inner tube
  - Tensioned HTD belt to prevent slipping and tearing
  - Slot to maintain tension in the system
- **Carriage**
  - There are two bearings on the bearing blocks for better load distribution
  - Carriage is attached to a large plate to distribute load across the arm

Intake



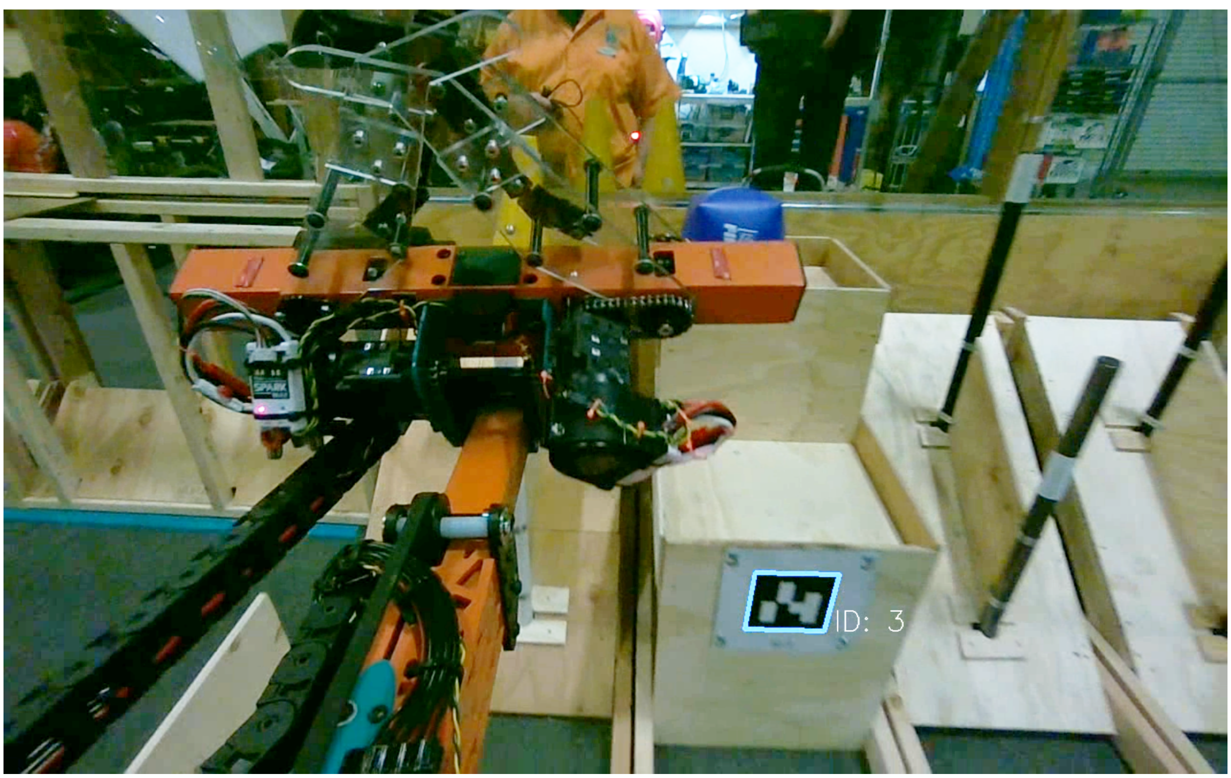
- **Pinchers**
  - Lightweight design with full width pick up range
  - Driven by 1 NEO geared down to 20:1
  - Banner reflective sensor to automate quick and reliable pick up
- **Wrist**
  - Dead axle ½in Thunderhex shaft attached to REV through bore encoder
  - Powered by a NEO attached to a 25:1 max planetary gearbox and 32:12 #25H chain reduction

III. Programming



Vision & Pose Estimation

- Fully custom vision pipeline that runs on a Linux coprocessor
- 30hz AprilTags capture and pose estimation (25ft max detection distance)
- Annotated video streaming and recording capabilities
    - Videos stay playable even if recording gets stopped by loss of power
- Live updating of vision configurations through local network
- Supports the use of depth information using a Realsense D455 depth camera
- Extremely accurate & precise
    - Centimeter level accuracy & precision in the community
    - Useful position measurements even at the center of the field (<10cm of position error)
    - Dynamically vision measurement trust on a per-tag basis allows for rapid pose estimate correction in the community (<0.2s from a complete loss in pose) with smooth pose estimates throughout the field
- 3D pose estimation
    - The entire pose estimation stack is run in 3D
    - Pose estimate remains robust while going over the bumps and charging station



Driver Assists

- Centralized, Simple Controls
  - The operator selects the wanted scoring position in a grid
  - The driver, controls (almost) everything else
    - Scoring a piece only takes 3 button presses:
      - Left Paddle: Auto Aligns Robot
        - Utilizes the operator's selected scoring position along with the position and velocity of the robot to select where to align the robot
        - The autoalign code is robust enough to be triggered from the opposite side of the field
      - Right Paddle: Deploys mechanism to scoring position
        - Utilizes the operator's scoring selected scoring position to deploy the mechanism to the correct state
      - Left Bumper (Press): Opens the intake, dropping the game piece in the selected position
      - Left Bumper (Release): Retracts the mechanism
        - Automatically closes the intake after the mechanism has retracted a sufficient amount
    - Station Pickup
      - Right Paddle: Deploys the mechanism to the pickup position
        - This is the same button that is used to score. The robot utilizes it's pose estimate to infer which action the driver wants
      - Proximity Sensor Detects Game Piece: Intake is automatically closed, and the mechanism is retracted
        - Grabbing force is determined by the selected scoring position
  - Controls are carefully designed to ensure the drive rarely (if ever) has to take their hands off the sticks

- Easy-to-configure mechanism states with collision avoidance
  - Uses inverse kinematics to convert from two-dimensional Cartesian coordinates to mechanism positions
  - Collision avoidance assures that it is not possible to drive the intake into the ground or field elements in the scoring/pickup area

Auto Balance

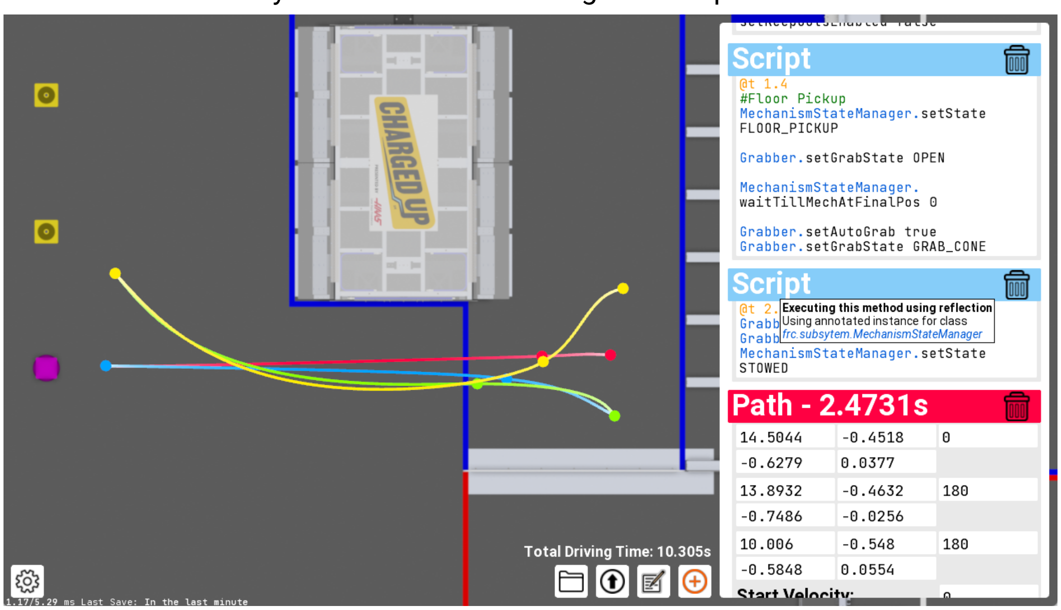
- Hybrid Odometry and Gyroscope based Auto Balance

- Utilizes the robot's vision-based pose estimation to drive most of the way to the center of the charge station
- Then uses the Pigeon 2.0 gyroscope sensor to fine tune the balance

- Auto Align
  - Ability to autoalign to any scoring position & both the double pickup stations
    - The chosen target is inferred by the robot's velocity and position
  - The path is generated asynchronous (in ~50ms on the roboRIO 2) and seamlessly takes over control from the driver when it finished
  - Utilizes the same, robust path planning that we use for autos

Programming Workflow

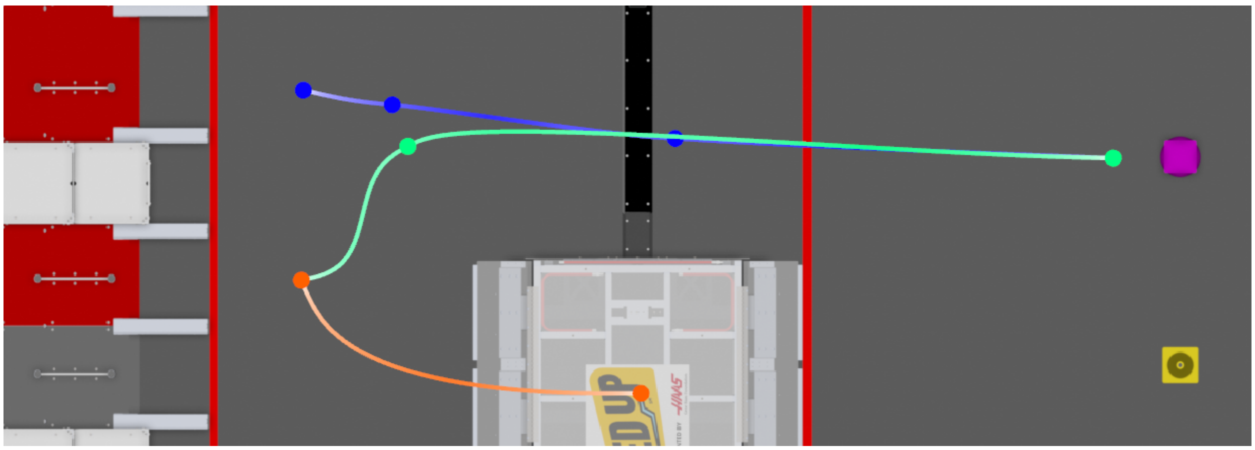
- Logging Everything
  - AdvantageKit Logging is used to record *all* the inputs and outputs of our robot code
  - The camera stream is recorded to allow for easy debugging of vision issues
- AutoBuilder
  - Developed by our team, fully open source, with extensive documentation[1]
  - Allows for rapid iteration of autos
    - Autos are deployed in ~2s, while the robot is running
    - Paths as well code executed on the robot can be modified without a full code deploy
    - Odometry is streamed to the robot in real-time to be able to visualize exactly how the robot is driving it's auto paths



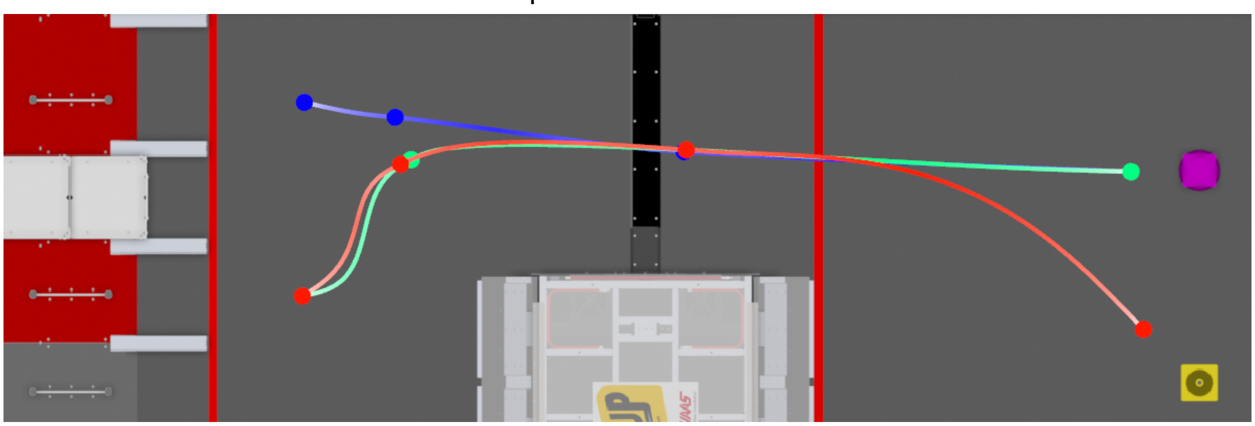
[1]https://github.com/FRC3476/AutoBuilder

Autos

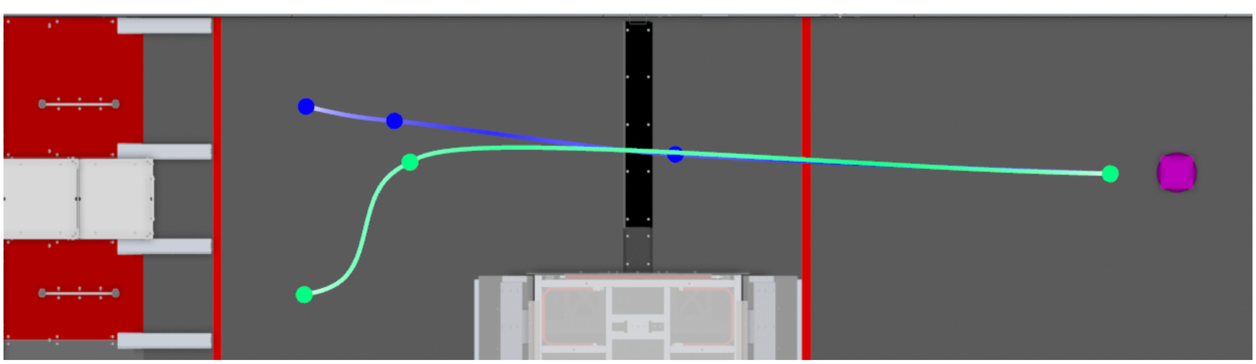
- **18 Autos**
  - Autos are shown for the red alliance. Each auto has a red & blue version
  - **Bump Side**
    - 2 Scored + Balance



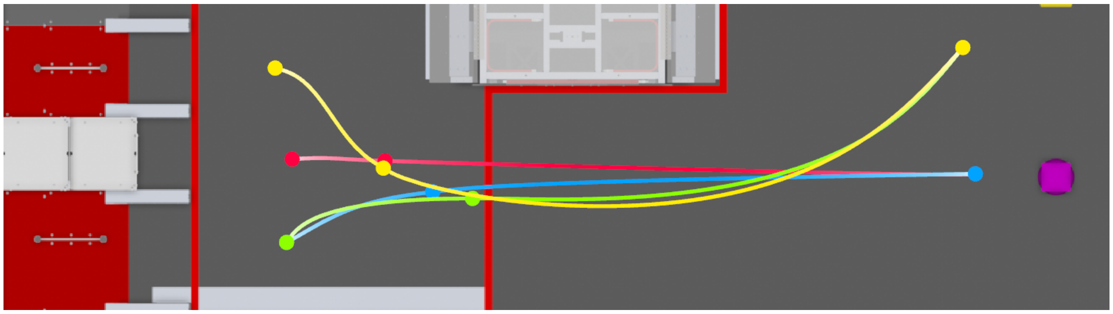
    - 2 Scored + 1 Pickup



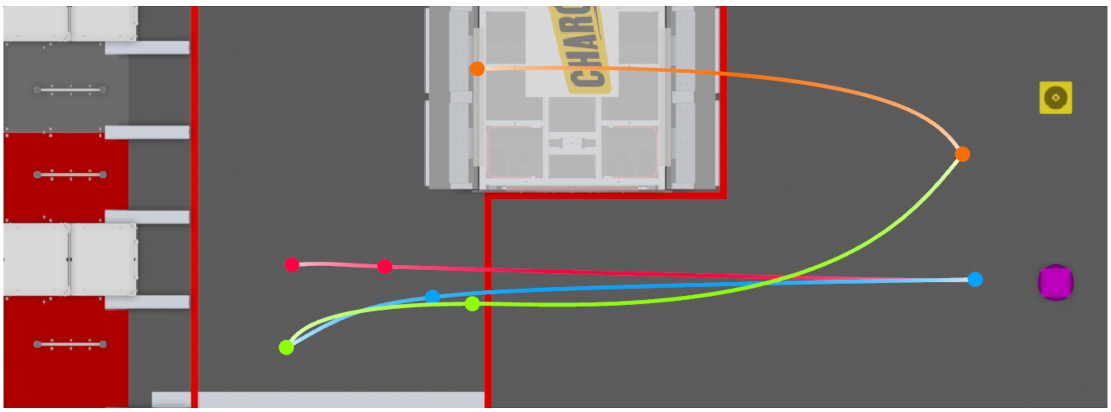
    - 2 Scored



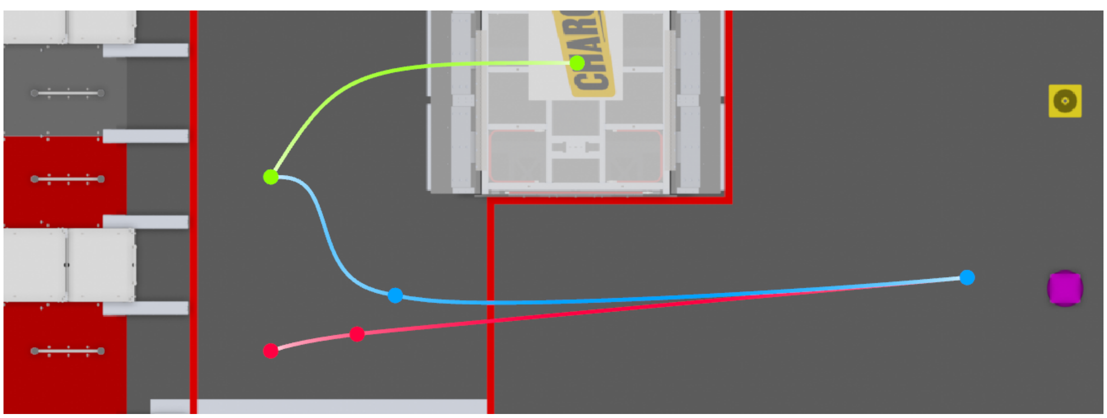
- **Human Player Side**
  - 3 Scored



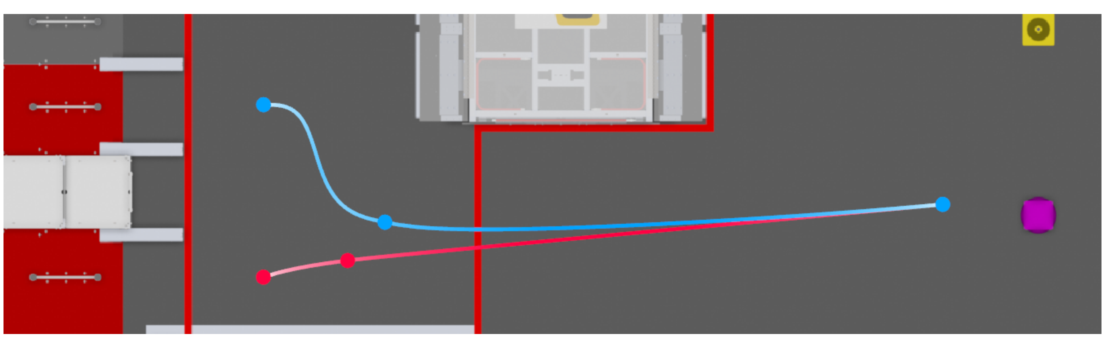
  - 2 Scored + 1 Pickup + Balance



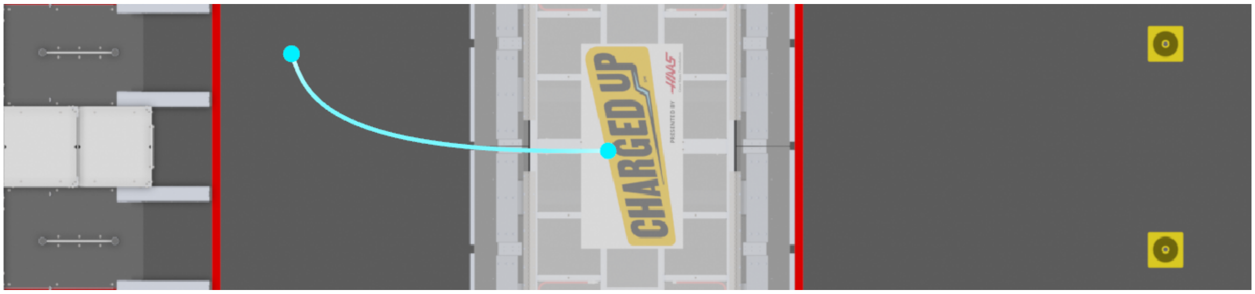
  - 2 Scored + Balance



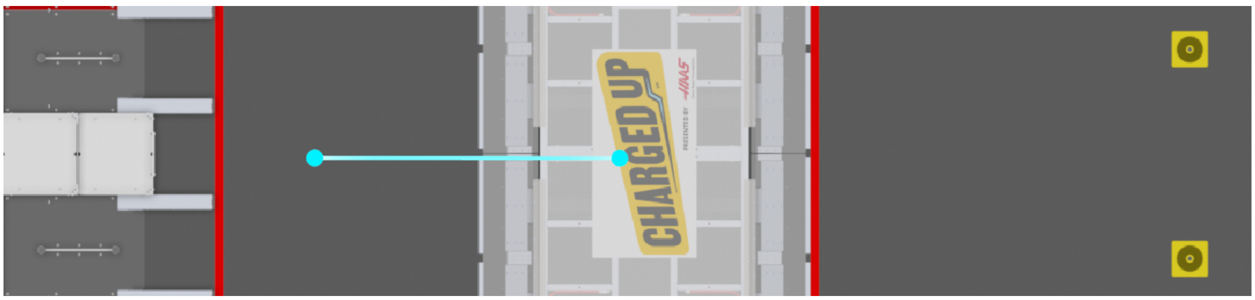
  - 2 Scored



- **Center**
  - 1 Scored + Balance (HP Side Cone)



  - 1 Scored + Balance (Cube)



  - 1 Scored + Balance (Bump Side Cone)