2023 Season Robot

DOFFLE

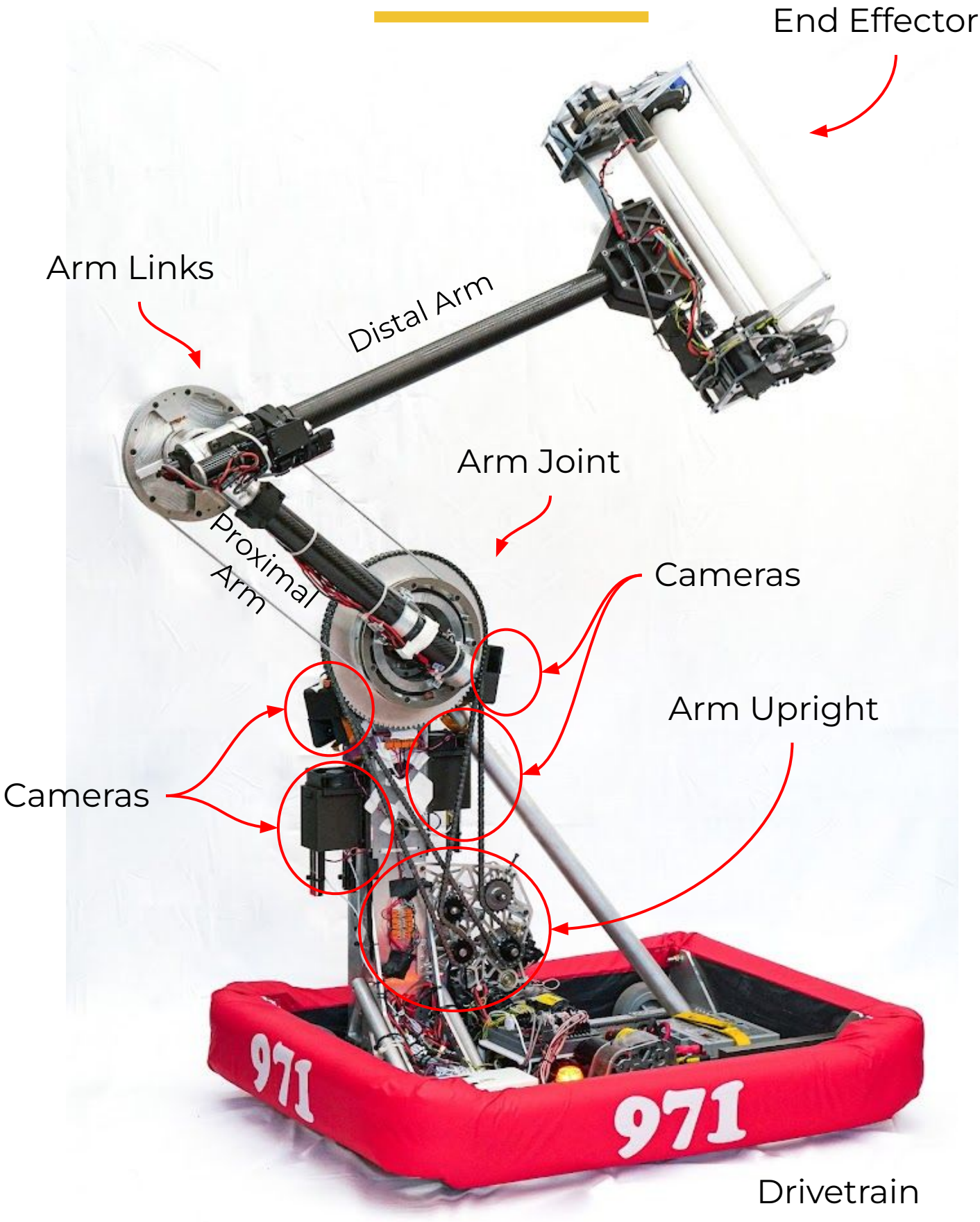
FRC971 2023 Technical Documentation

Contents

Contents

Contents

DOFFLE


End Effector
Arm Links
Distal Arm
Arm Joint
Proximal Arm
Cameras
Arm Upright
Cameras
971
971
Drivetrain

DOFFLE

Mechanical:

- 4 DOF arm can pickup and score from any location – front or back
  - Shoulder and elbow provide reach for high nodes
  - Roll joint reorients the end effector to pick up both cones and cubes from either the front or back
  - Wrist joint orients cones optimally for scoring, whether they were upright or tipped over
  - Low inertia and mass to quickly move without tipping
- End effector for any game piece in any orientation
  - “Touch it, own it” regardless of driving speed or angle
  - Rollers pinch cones by either the tip or flange
  - Large width reduces necessary precision
  - Compliant to bend instead of break
- Fast, agile, 6 motor, west coast drive minimizes cycle time
- 4 localization cameras provide 360 degree visibility for detecting AprilTags anywhere on the field
- Custom drive station button board and spring-loaded pistol grip controller for ease of use and improved robot control

Electrical:

- Custom PCBS
  - Custom sensor and roboRIO (Spartan) boards enable all connections to be crimped for reliability
  - Pi Power Board provides local regulated power to each of 6 Rock Pi coprocessors
  - Button Boards interpret signals for drivestation controllers

Software:

- April Tags
  - SLAM Mapping
  - Live Detection
- Game Piece Detection using Machine Learning
- Arm Control
- Autonomous

Mechanical

- Drivetrain
- Arm Uprights
- Arm Links
- End Effector
- Cameras
- Drivestation

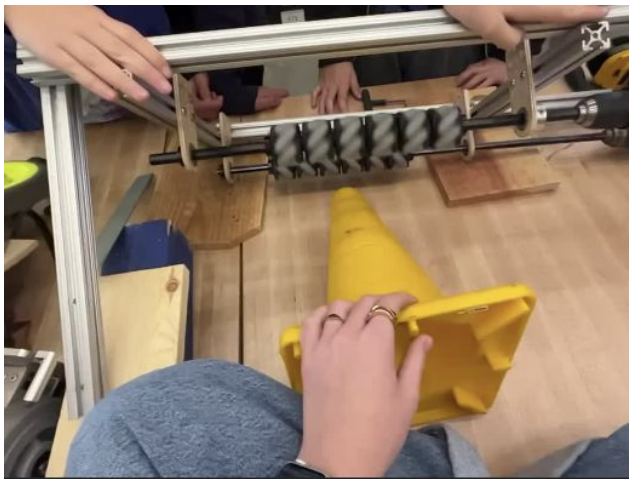
Why We Prototype

971 believes in fostering a culture of innovation. Every idea is given a chance to be considered or tested.

By empowering individuals with varying expertise to come together to innovate, they bring with them unique perspectives, ideas, and ways of thinking. This diversity often leads to more creative solutions that consider a wider range of possibilities and challenges.

It is also important to be flexible and adaptable as new approaches are learned. Effective prototyping enables the team to evolve and pivot as necessary.

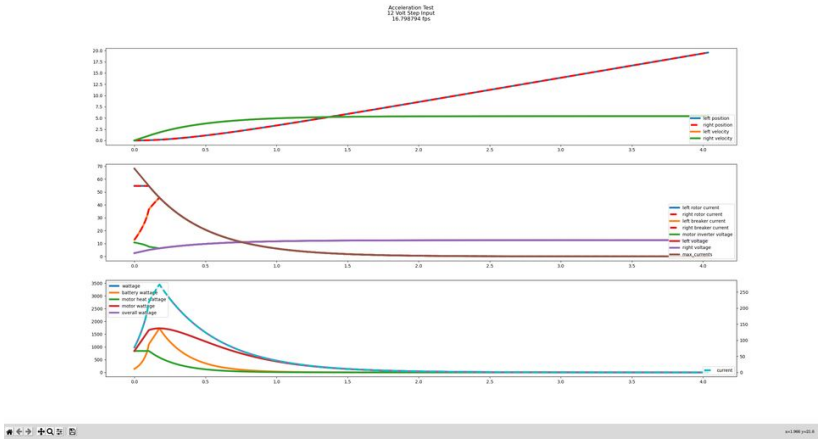
Following this process creates a culture of innovation and continuous improvement. It is a critical aspect that enables the team to design unique robots that allow a strong partnership between students and mentors to build students technical and leadership skills.



Prototyping

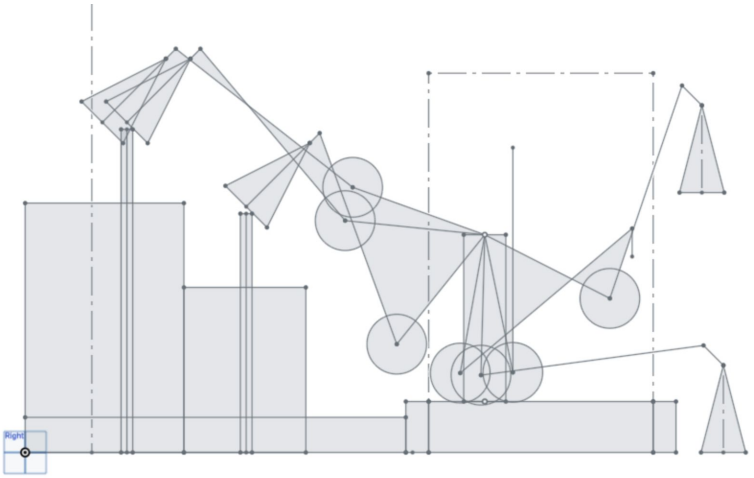
Drivetrain

- Performed extensive simulations of drivetrain performance under the limits imposed by battery and breaker models
- Primary design spec was minimization of sprint time given the current limits of the battery
- Tested effect of bumper height on ease of climbing the charge station



Arm Upright

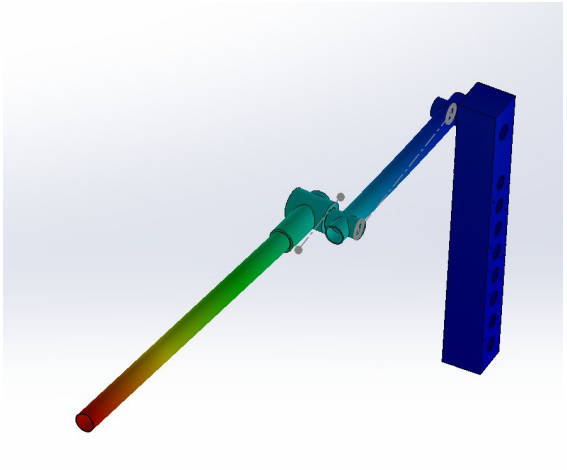
- Found a double jointed arm architecture that allowed for scoring and pickup on both sides of the robot
- Explored joint and gearbox locations and geometry to minimize backlash/hysteresis while maintaining low center of gravity



Prototyping

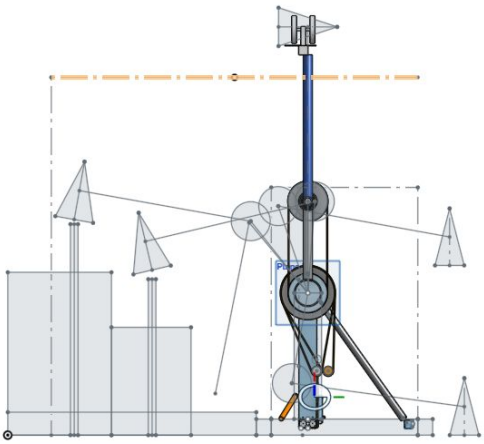
Arm Joints

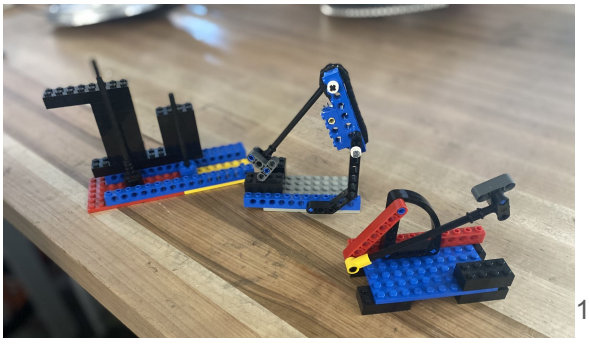
- Using 2018 arm as a model, refined and further developed mathematical model to determine rotational stiffness and natural frequency
- Set design specs for arm stiffness using the metric of natural frequency of oscillatory modes
  - 1st (vertical) mode: >4Hz
  - 2nd (lateral) mode: >10Hz
- Calculated and sized arm bearings, sprockets, and capstans to meet stiffness specs
- Validated potential designs through mathematical analysis and FEA simulation



Arm Links

- Created linkage geometry and chose link lengths using a simplified CAD model
- Made Lego models to demonstrate and visualize scoring positions and desired ranges of motion
- Estimated center of gravity location with arm extended using approximated component weights

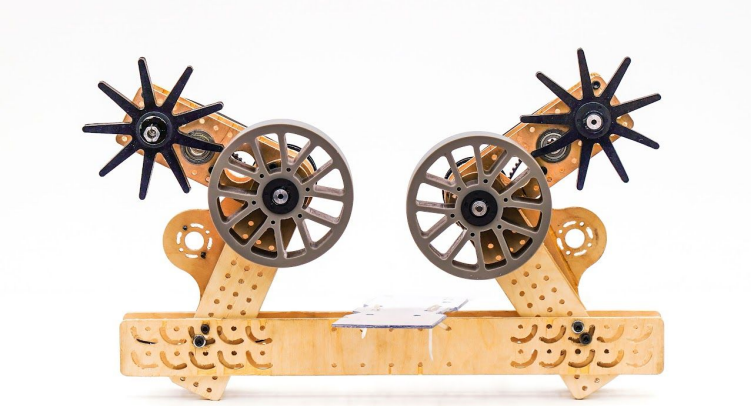


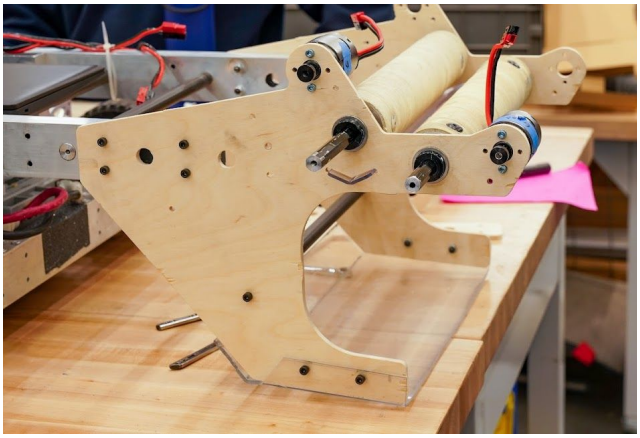


Prototyping

End Effector

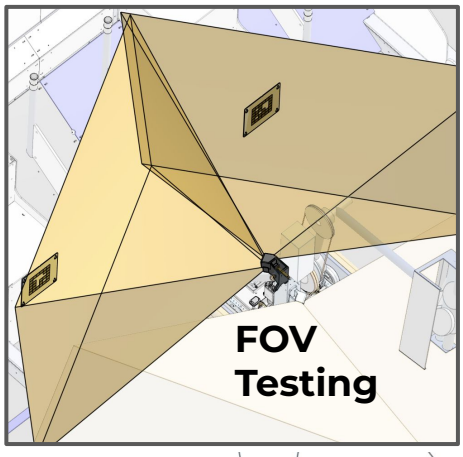
- Tested designs using both vertical and horizontal rollers and varying roller material
- Prototyped geometry and roller locations using 80/20 and plywood

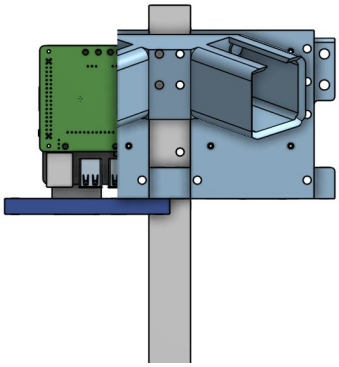




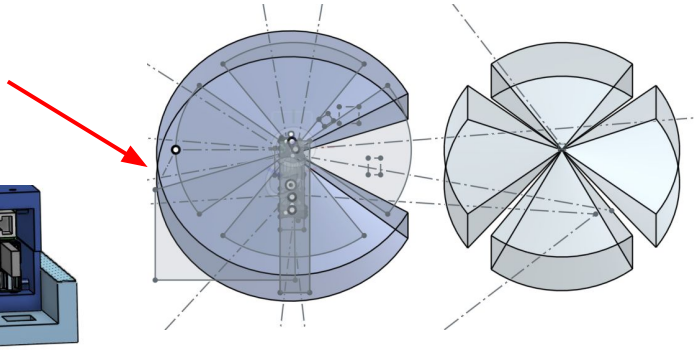
Cameras

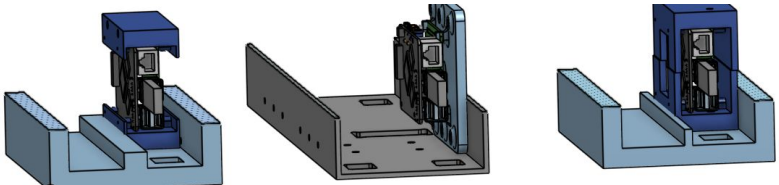
- Modeled camera FOV in CAD
  - Desired visibility of at least two tags at all times
- Explored designs for:
  - Thermal cooling
  - Ease of serviceability
- Experimented with placement of driver camera to maximize 360 degree visibility with one fisheye lens





Initial pole mount design

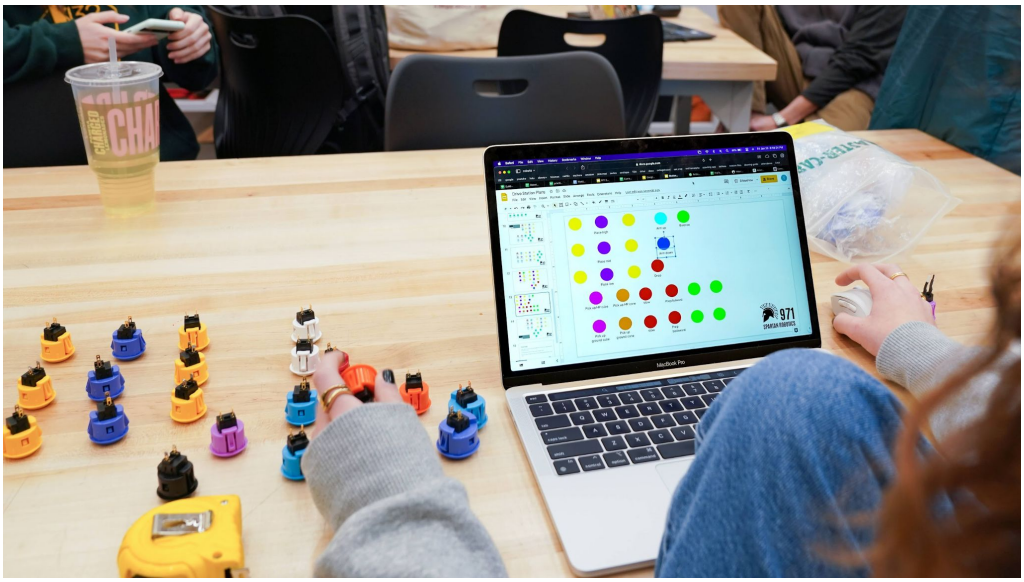


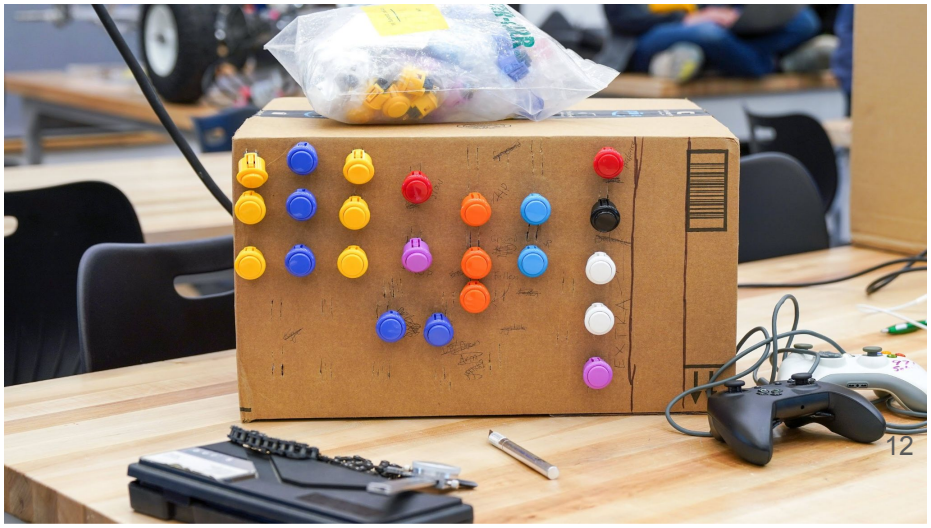


Prototyping

Drivestation:

- Considered several variables from this years game and strategy team's input
- Went through several rounds of iteration and rough models to find the best placement
- Adapted to a design that would best accommodate our robot





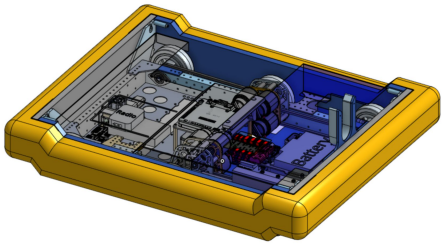
Drivetrain

6 Falcon drivetrain has high top speed (16.8 ft/s) and acceleration

8.28:1 gear ratio

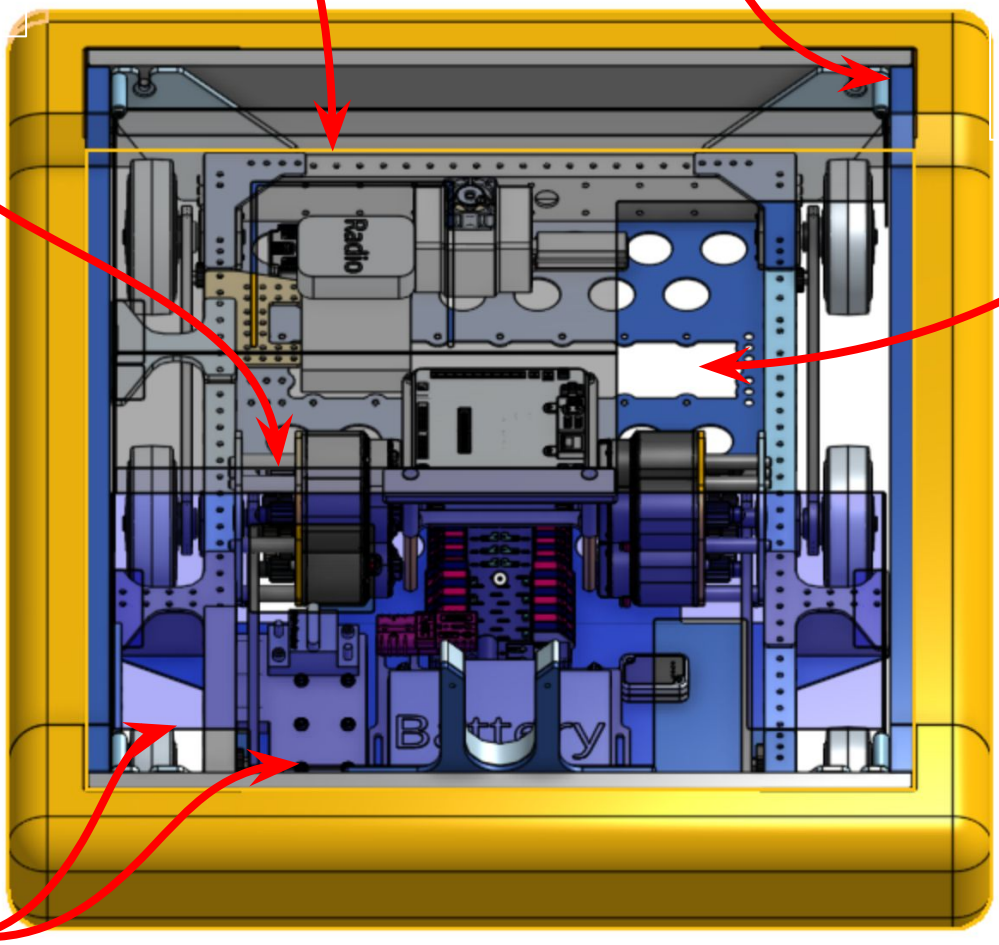
Packaged in a rotated fashion to lower CG

Lexan guard to prevent unwanted game pieces from falling into the drivetrain



"Boat" bumpers allow for easily crossing the charge station while still maintaining advantage against pins/pushing

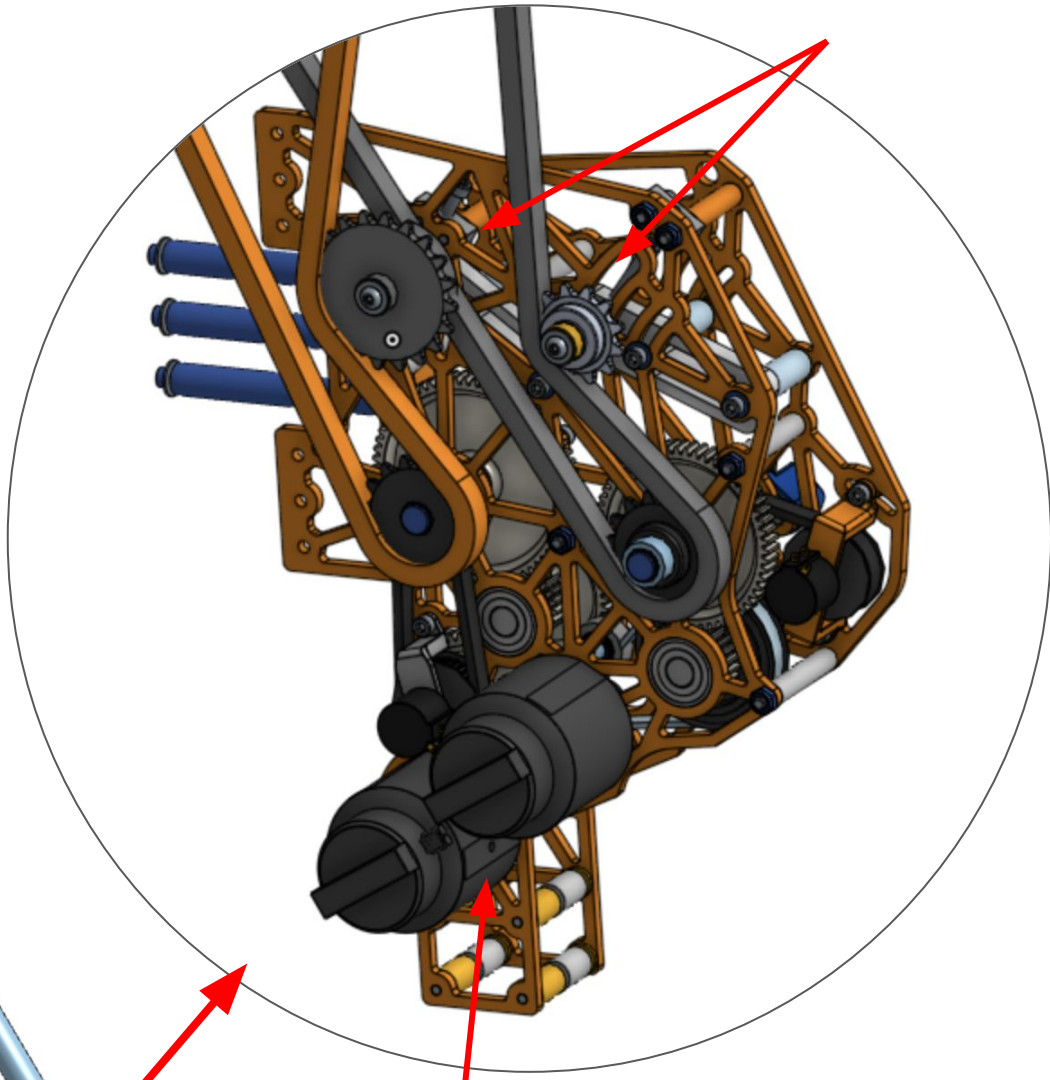
Attachment for support tube and arm upright integrated into design

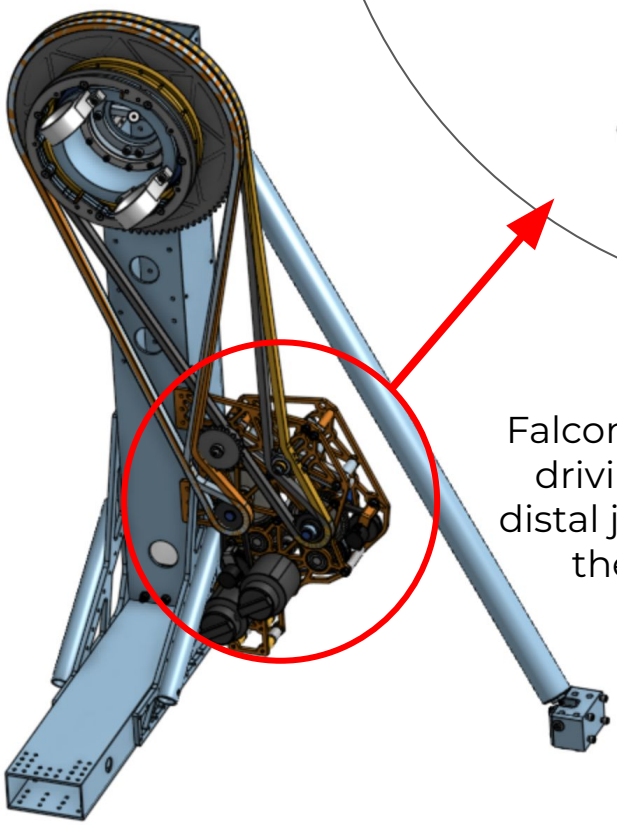


25 lbs of ballast to lower and center robot CG

Arm Upright

Tensioner idler sprockets
(can rotate freely)

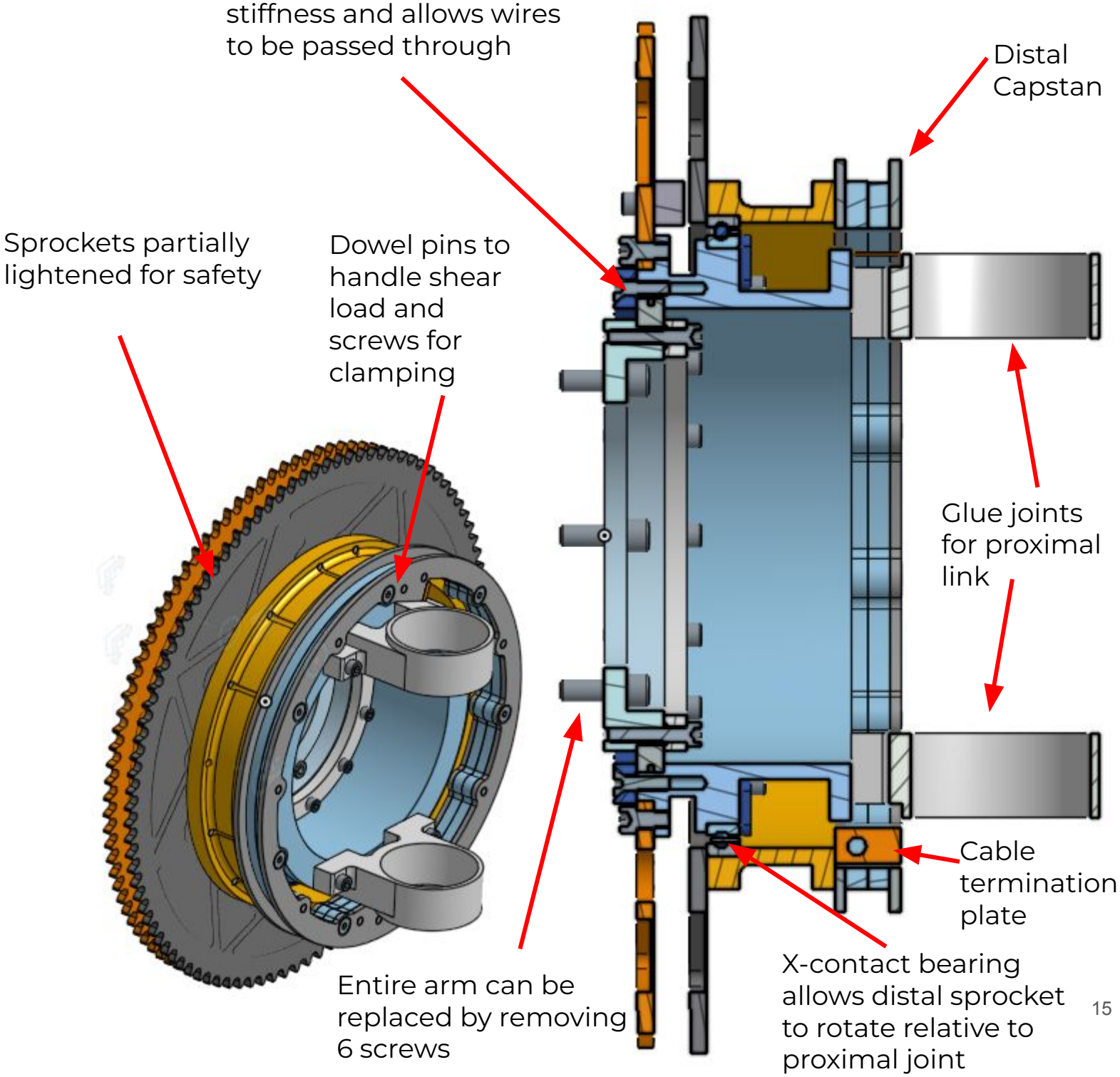




Falcon motors, one each for driving the proximal and distal joints, are packaged at the base to lower CG

Proximal ratio: 55.42 : 1
Distal ratio: 105.86:1

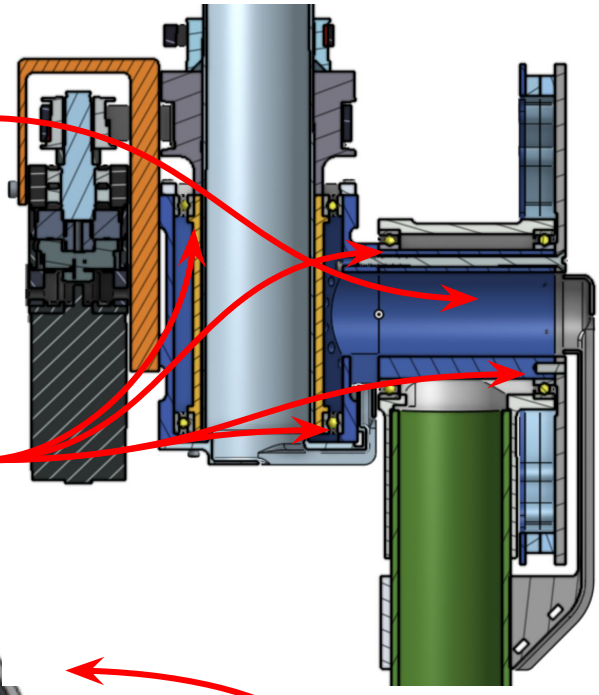
Arm Joint


Large diameter cross-roller bearing provides extremely high stiffness and allows wires to be passed through
Distal Capstan
Sprockets partially lightened for safety
Dowel pins to handle shear load and screws for clamping
Glue joints for proximal link
Cable termination plate
X-contact bearing allows distal sprocket to rotate relative to proximal joint
Entire arm can be replaced by removing 6 screws

Arm Links

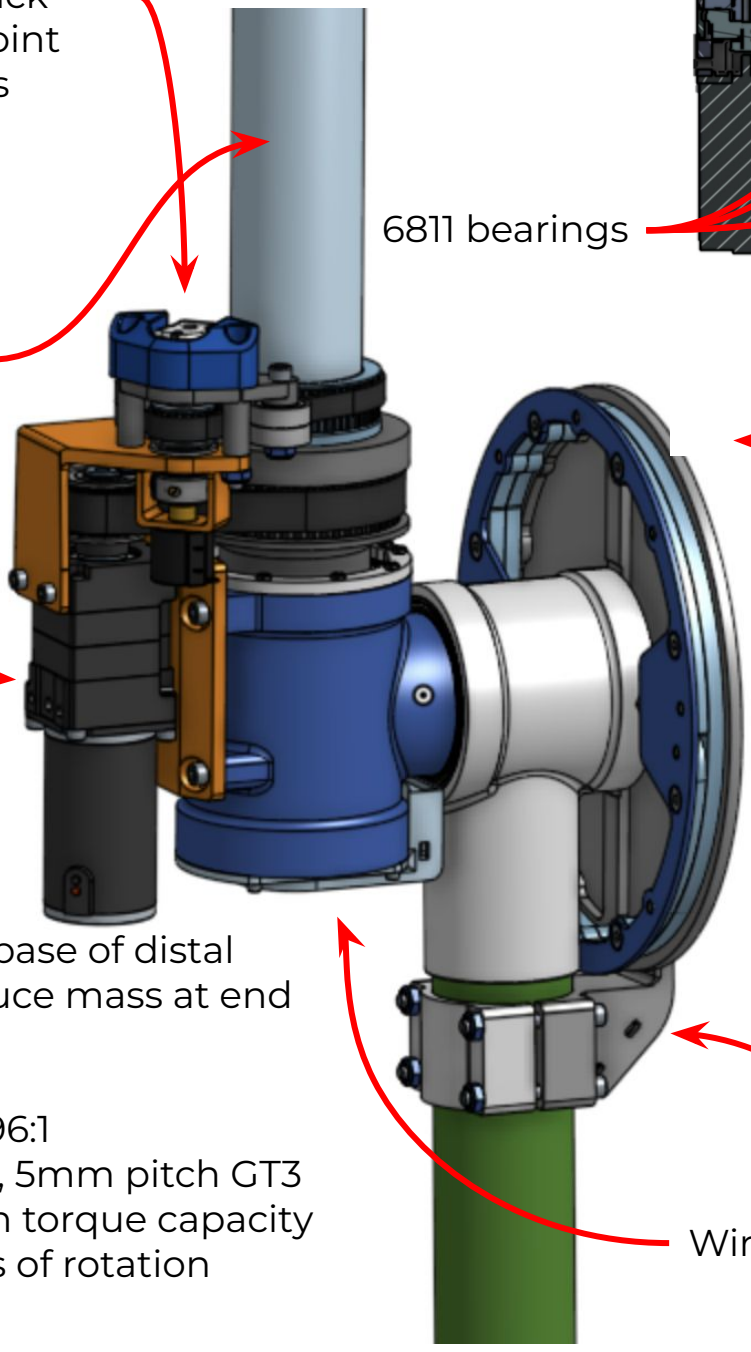
Large diameter shaft connects captstan to distal link with high stiffness

Non-driven sensor shaft to maintain accurate feedback even if the roll joint driving belt slips



6811 bearings

Carbon Fiber tubes chosen for stiffness to weight advantages



Capstan

- 3/16” 7x19 cable
- Cable drive for increased stiffness over chain
- +/- 350 degrees range of motion

Roll joint

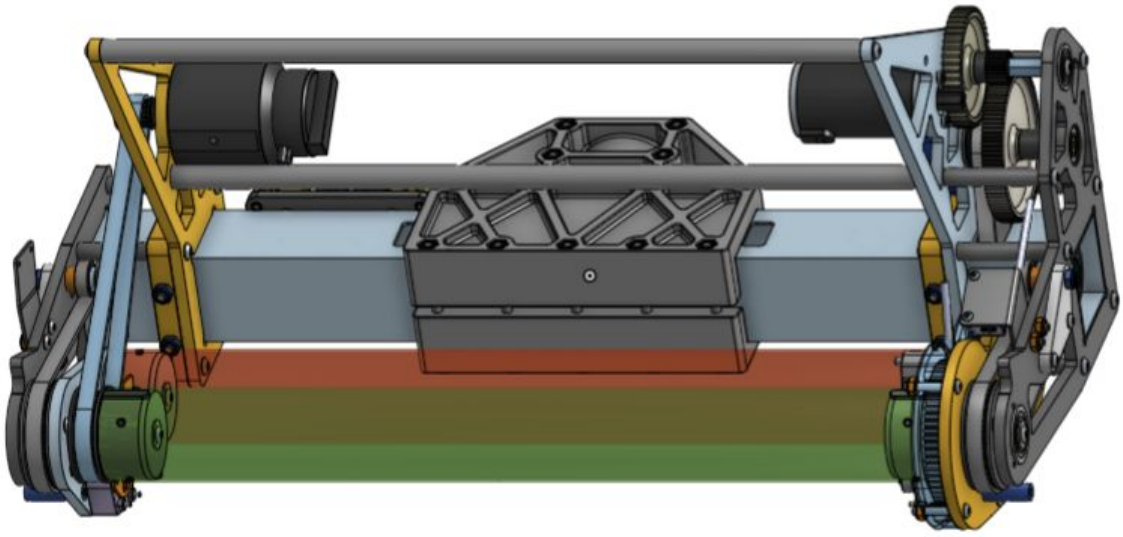
- Located at base of distal joint to reduce mass at end of the arm
- BAG motor
- Gear ratio 96:1
- 15mm wide, 5mm pitch GT3 belt for high torque capacity
- 335 degrees of rotation

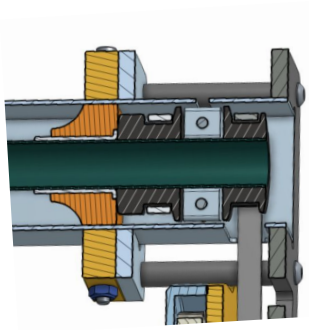
Wire guards

End Effector

1st Iteration Specifications

- ~ 10 pounds
- 17.5 in of intaking space





Rollers:

- 2in OD polycarbonate rollers
- 17.5 in of intaking space

Wrist:

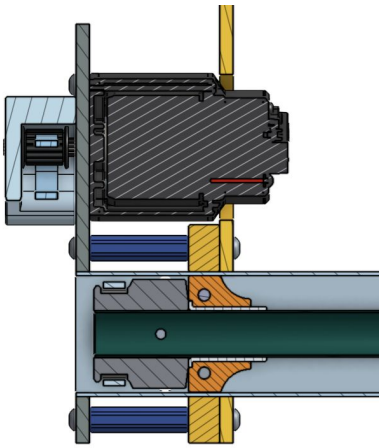
- Back roller rotates along the axis of the front roller
- ~150 degree range of motion
- Clamping pulleys inside the main tube (on either side) for wrist

Learnings from 1st iteration:

- Need a larger range of motion on the wrist for easier release of cones onto the pole
- Belts sometimes skipped → need more tensioning and switched from GT2 to HTD
- Clamping pulleys were slipping, need to put bolts through pulleys and tube

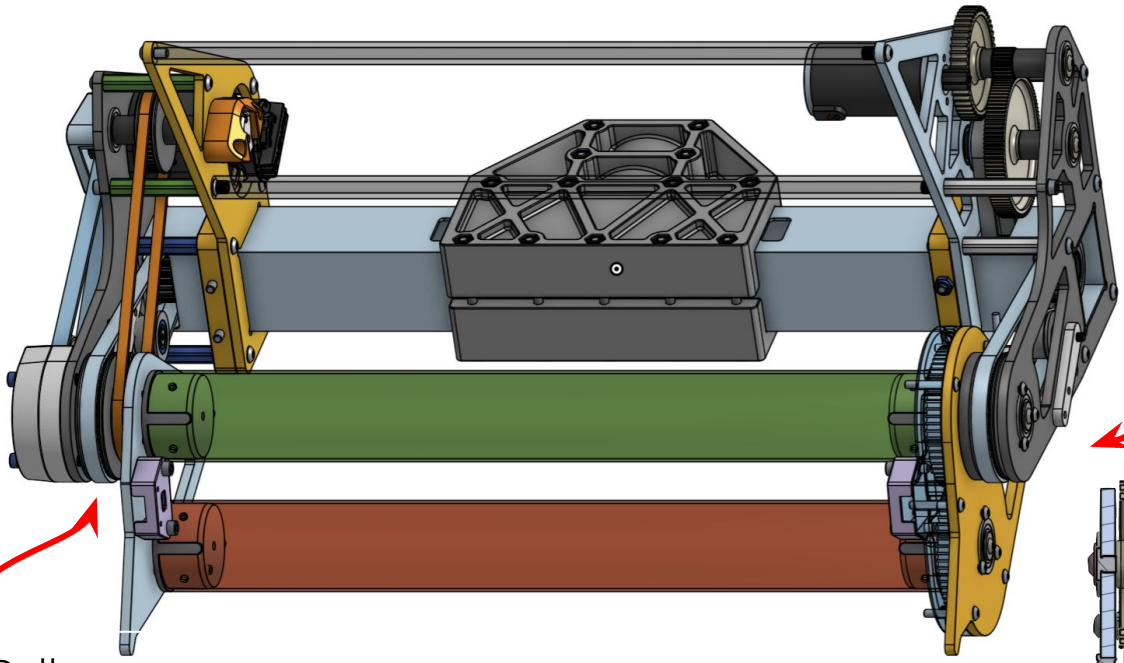
End Effector

Current Iteration Specifications



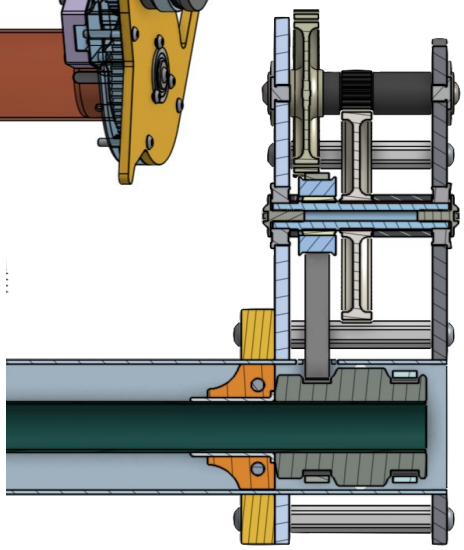
Wrist:

- Powered by Bag motor, 1:97.78 in 4 stages
- Near 360 ROM
- Large shaft inside the main tube to power movement from both sides



Rollers:

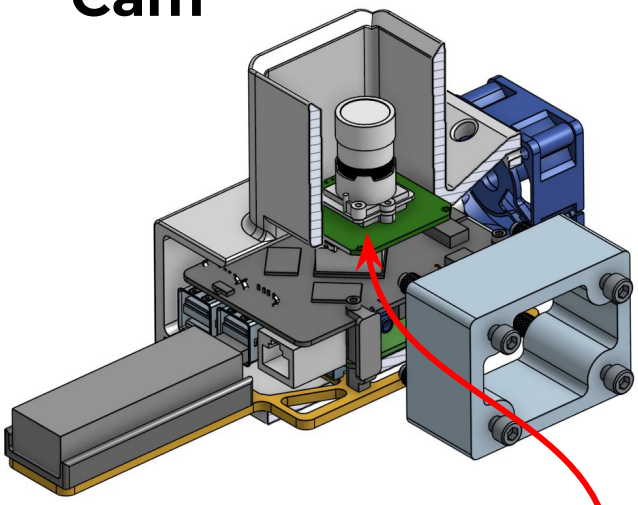
- Powered by Falcon motor 1:3 gear ratio
- Belt is on the outside of the rollers to prevent interference with wrist



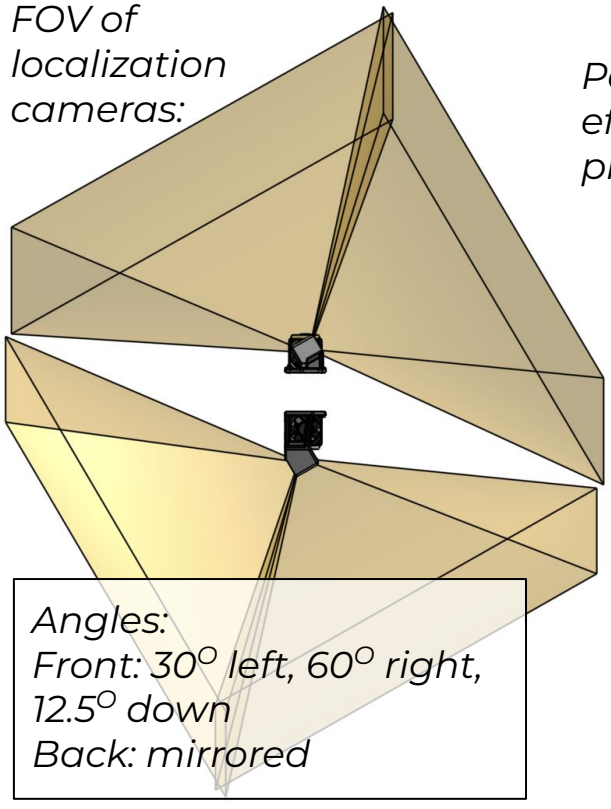
Cameras

Current Iteration Specifications

Machine Learning Cam

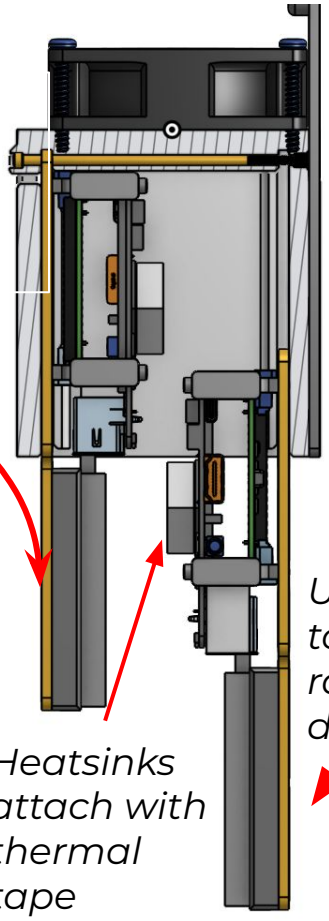


Points at end effector for game piece detection.



FOV of localization cameras:

Angles:
Front: 30^{O} left, 60^{O} right, 12.5^{O} down
Back: mirrored



Pis mounted on sliding plates

PI BOX

USB guard to prevent rattle and damage

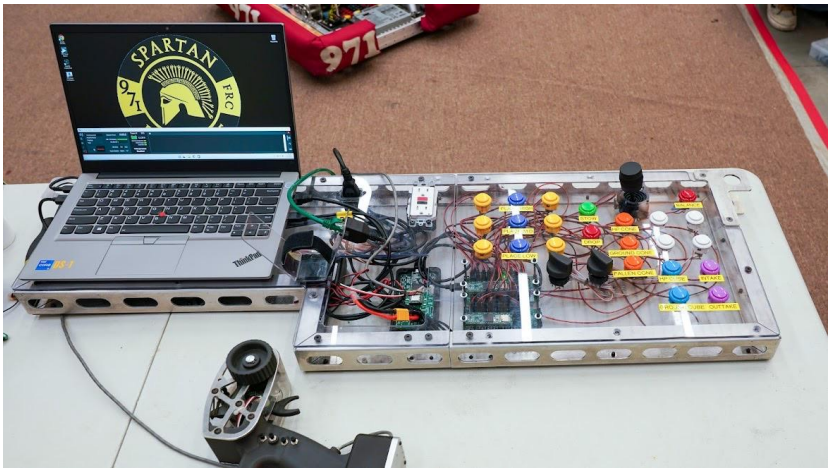
Heatsinks attach with thermal tape

Specs:

- 4 localization cameras (92^{O} FOV) for AprilTag detection.
- 1 camera pointed at End Effector to detect game piece position, uses machine learning models.
- 4 fans total mounted to each Pi for cooling.

Driver station

Current Iteration Specifications



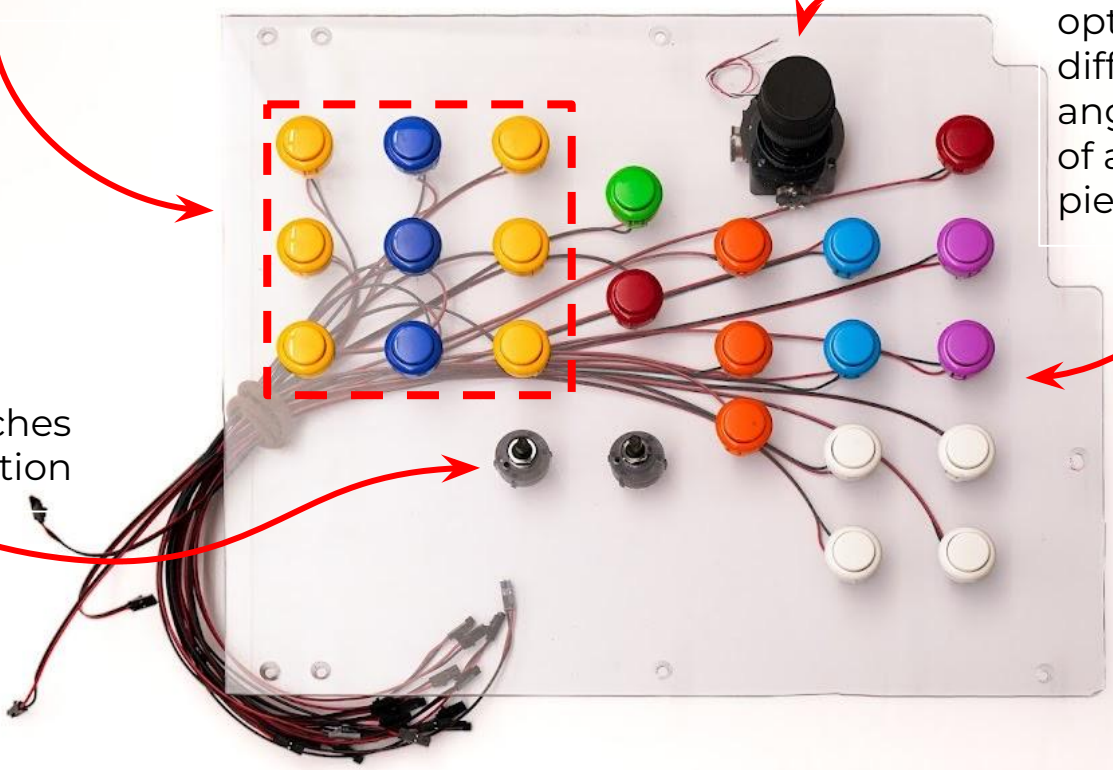
23 custom spring loaded buttons

Configurable 3 axis joystick for arm movement

Dedicated array for placement, aligns arm left/right depending on placement

Placement options for different angles/options of all game pieces

5 position rotary switches for arm motion

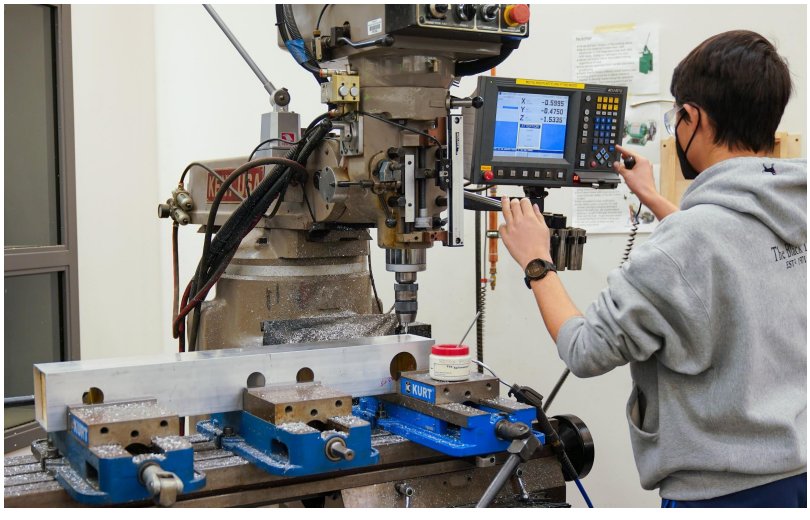


Manufacturing

- Process:
  - All parts add to parts list methods to track progress with material and machine information
  - Drawings printed
  - CAM for parts → 3 step process to make sure CAM is correct
  - Sheet output for router
  - Students make parts
  - Deburing and filing
  - Inspection of all parts to make sure they are in tolerance

- Special parts made:
  - 95 and 96 tooth #35 chain sprockets made on the router + mill
  - All bearing-connected parts turned and milled. Two large (>5”) bearings were connected to one part
  - Billet parts made on CNC mill at Blue River, one of our sponsors, with students going onsite to be involved in the process of milling them

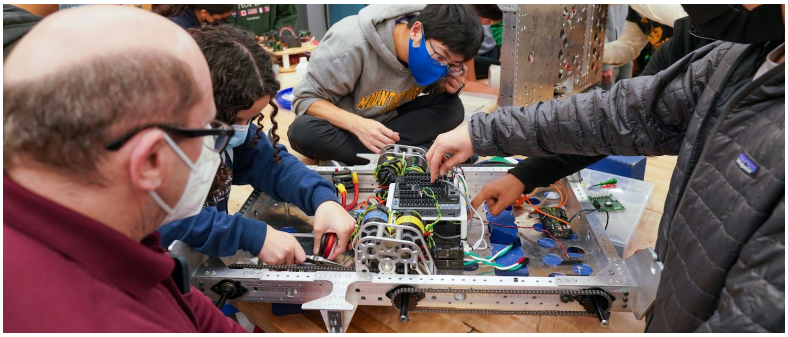
Billet part being made at Blue River

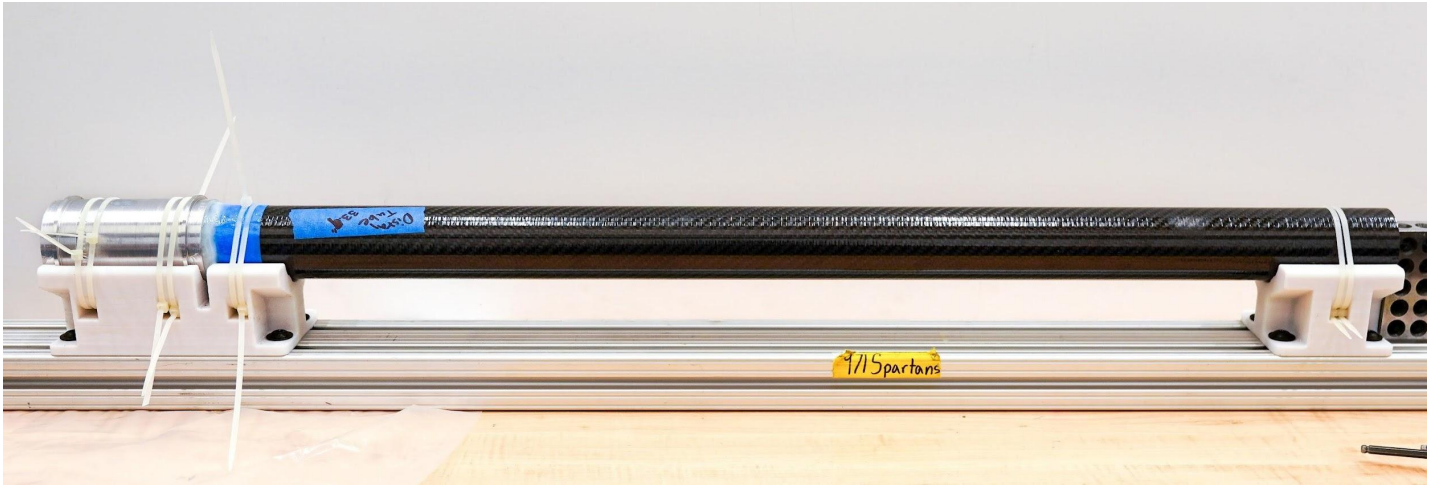


Justin facing some of the tube down to 0.0625” walls

Design for Assembly

- All screws were made accessible
- Bearings are easily clamped/unclamped
- Large hole in the center left for wires to feed through.
- The end effector is clamped onto the arm via 13 screws (easily interchangeable)
- Access to MIPI cable from every camera for assembly and wiring
- Used green loctite to prevent backlash on the gearbox shafts
- Designed large contact area to get stronger bonds with epoxy (instead of welding)
- Epoxy used since it can have comparable strength and gives us more flexibility in assembly





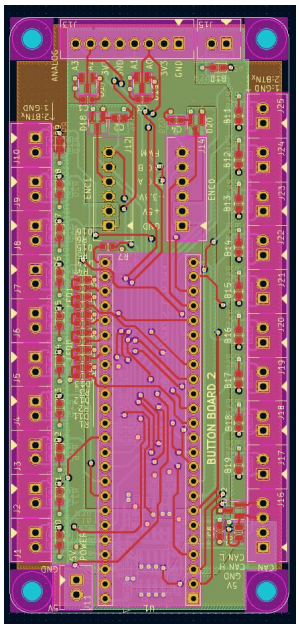
Electrical

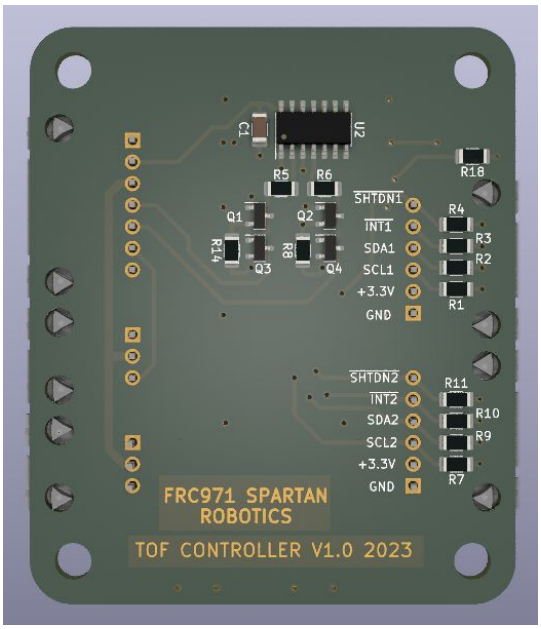
- Custom Boards
- Robot Wiring

Custom Boards

Design

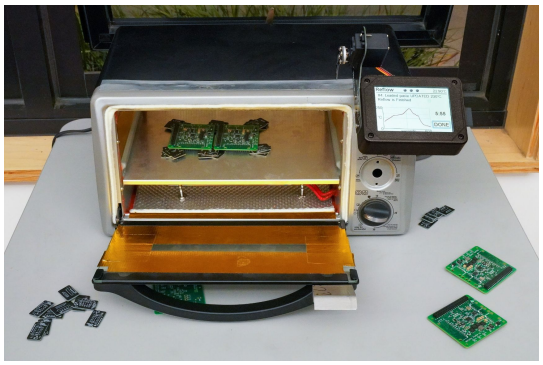
1. Take a recurring problem or a feature that we would like to have on our robot
2. Find all the features and build requirements
3. Design in KiCad
4. Build & Test

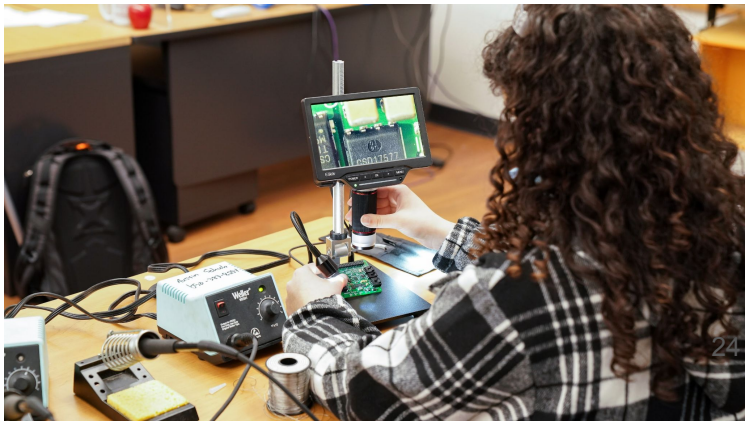




Manufacturing & Assembly:

- Used both paste masks and hand soldering
- 100+ total boards made
- Total boards manufactured:
  - TOF Board
  - Spartan Board
  - Optical Encoder Adapter
  - SRX Encoder Adapter
  - Potentiometer Adapter
  - Rock Pi Power Board
  - CAN Terminator Board
  - Beam Break Board
  - IMU Board
  - Button Board



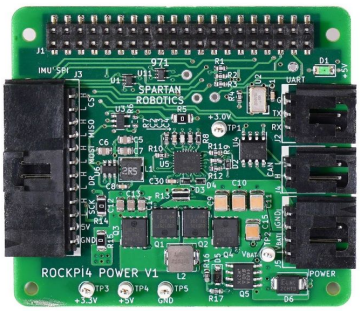


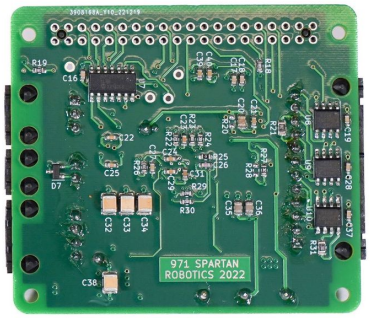
Custom Boards

Board Inventory: Interface & Power

Rock Pi 4 Power Board:

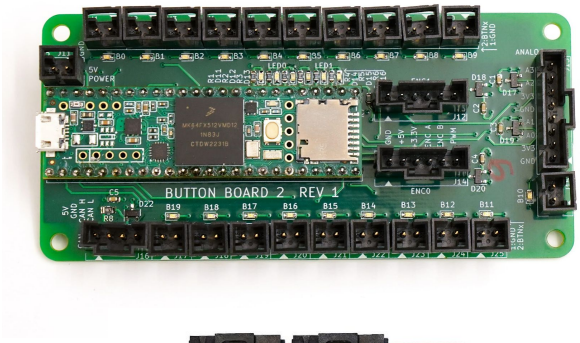
- Takes the unregulated power from the power distribution board
  - Turns it into a 5V supply (for the rock pi), a 3.3V and 3V supply (for the GPIO pins).
- Allows interfacing with IMU





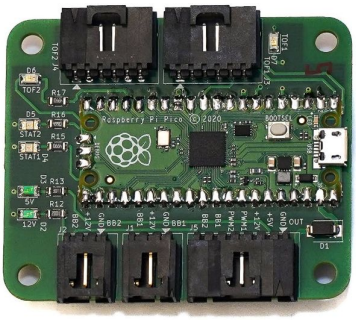
Button Board:

- Uses Teensy 3.5 microcontroller
- Total of three used in custom drive station
  - 1 is in the pistol grip, used for getting encoder data from the joysticks
  - 2 are used for buttons inputs



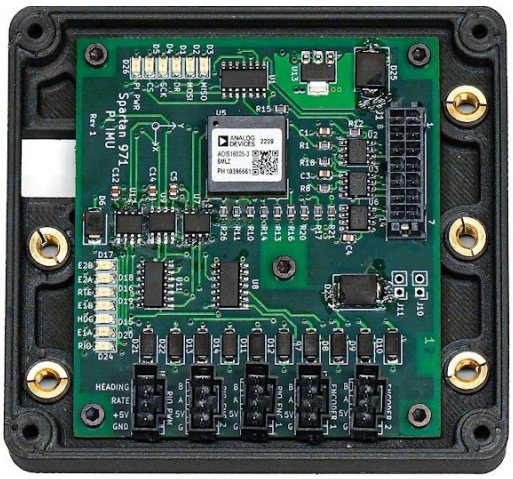
Time of Flight Board:

- Takes in 2 bream breaks and 2 TOF controllers
  - TOF controller measures the 'time of flight' of light that is reflected and returns distance
- Takes the output of the TOF sensor and turns it into something the roborio can understand



IMU Board:

- Uses the raspberry pi pico
- Transfers IMU (position) data to the imu raspberry pi
- Takes in the drivetrain encoders
- Outputs heading and rate to the roborio
- Used for localization

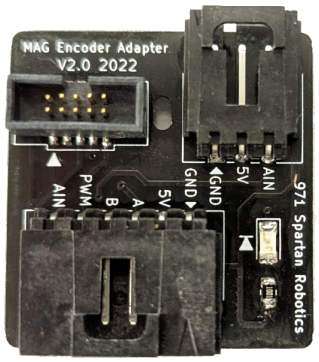


Custom Boards

Board Inventory: Adapter Boards

Mag Encoder Adapter:

- Combines the digital and analog inputs of both the mag encoder and the potentiometer into one connection that goes back to the Spartan Board

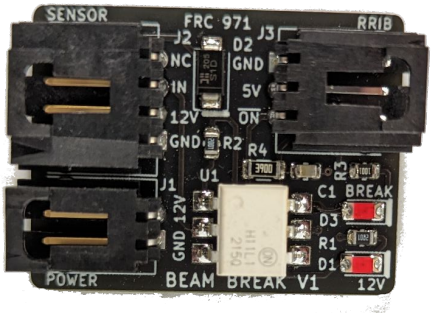


Shaft Encoder Adapter:

- Takes the insecure and weak connector on the optical shaft encoder and turns it into standardized molex connector system

Beam Break Adapter:

- Powers the beam break sensors on the robot
- Takes 12V from the VRM and sends it up to the beam break
- Outputs the digital signal from the beam break



Potentiometer Adapter:

- Mounts to the malformed face of the potentiometer
- Allows pots to be hot-swappable without soldering

Spartan Board V2.0:

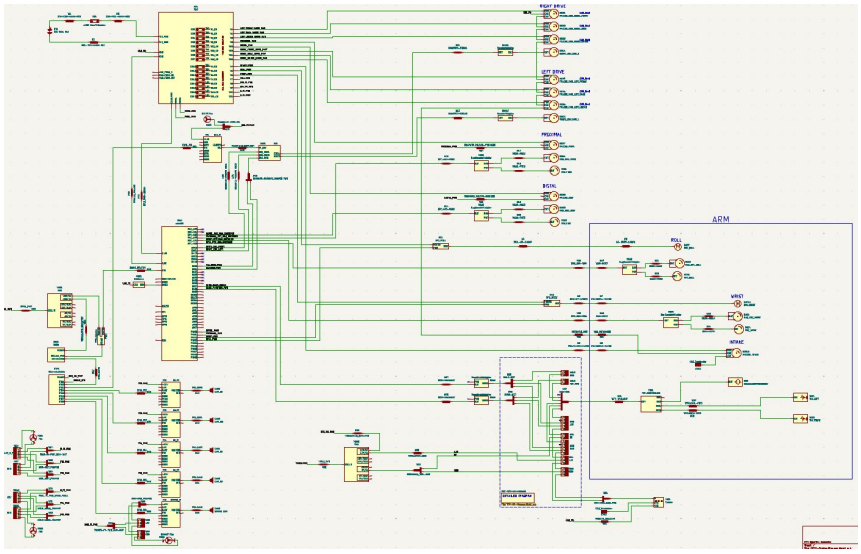
- Placed directly onto the roborio
- Converts the non-locking connectors into molex connector, allowing for a firm connection

Robot Wiring

Design Process:

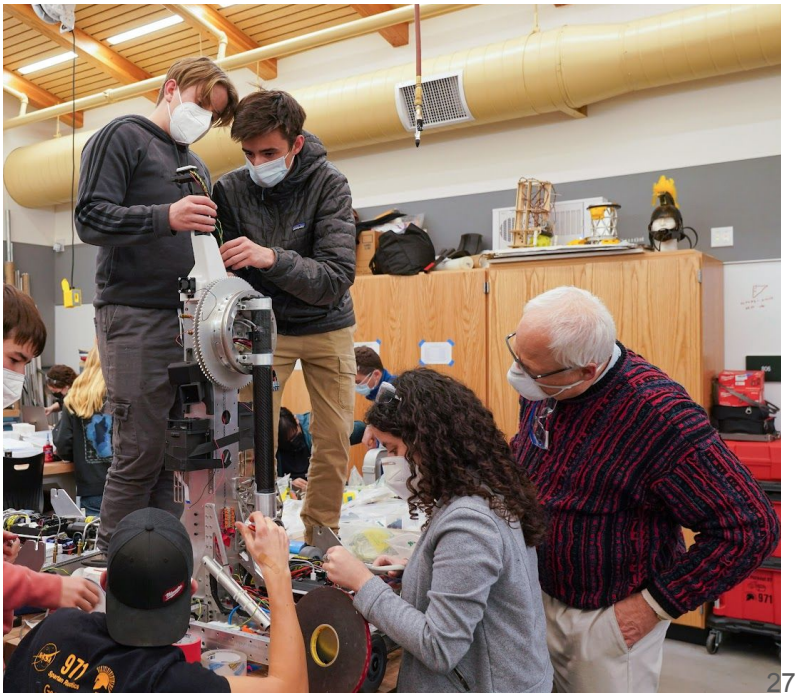
Planning:

- Drew up a full robot schematic
  - Includes all ports of PDB and roborio
  - Also includes sensors, motors, raspberry pis, etc.
- Measured lengths in CAD to get a understanding of how long our wires need to be.



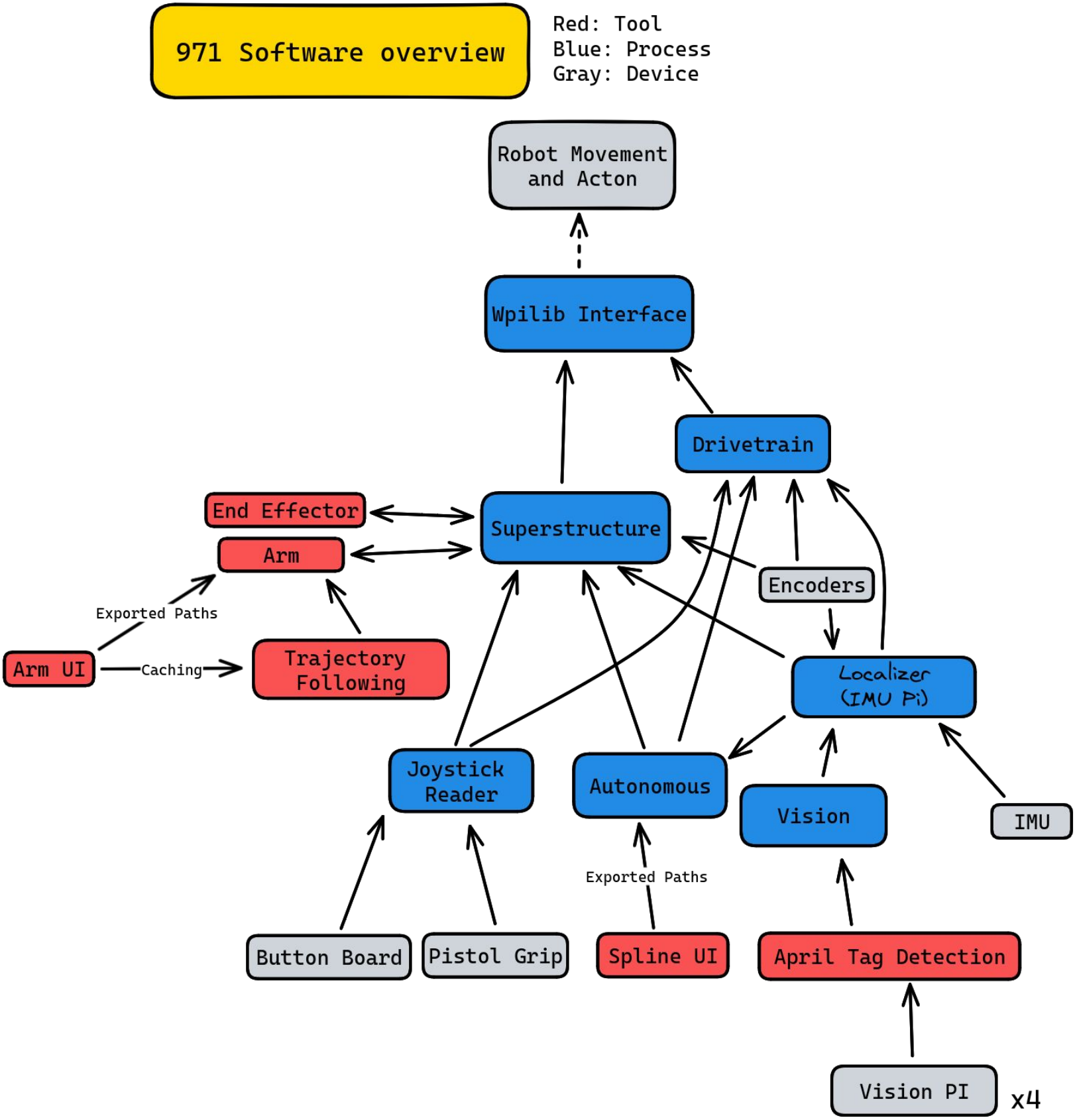
Wiring Process:

- Cutting and crimping the wires:
  - Used the system diagram to figure out what cables go where
  - Kitted the cables made
- Repairability:
  - Added connectors at each joint for easy disconnect
  - Standardized pinout for simplified testing



Software

- Software Overview
- April Tags
  - SLAM Mapping
  - Live Detection
- Game Piece Detection using Machine Learning
- Arm Control
- Autonomous

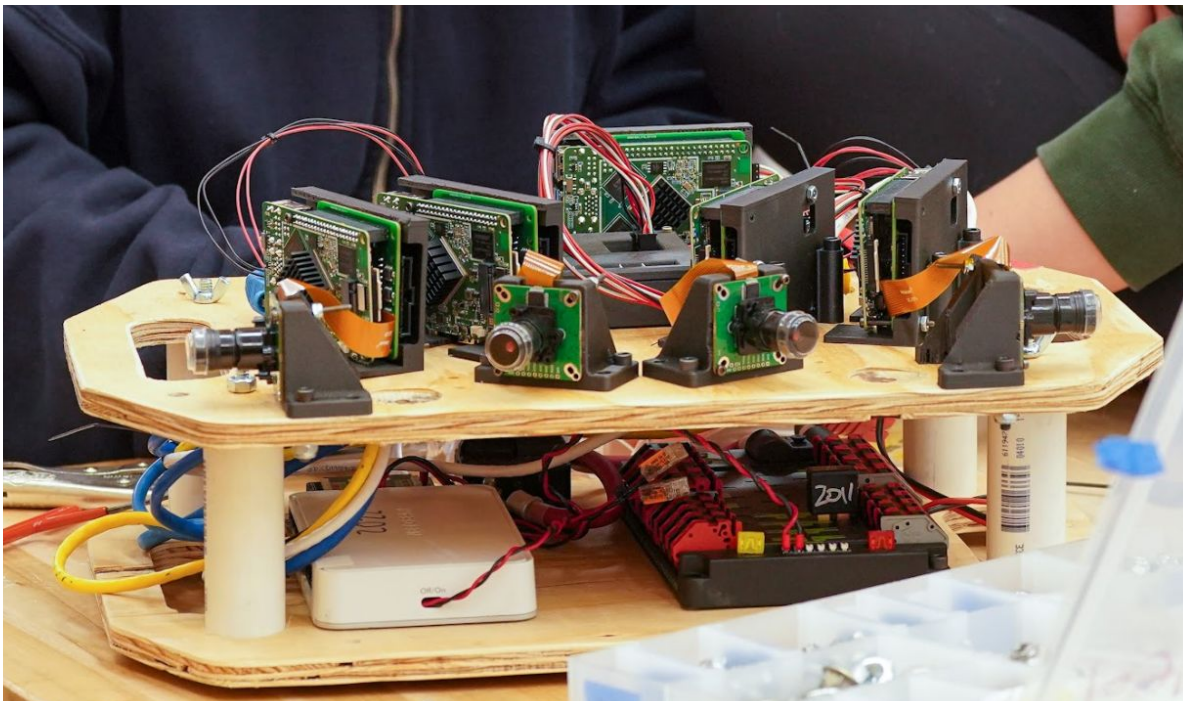

971 Software overview
Red: Tool
Blue: Process
Gray: Device
Robot Movement and Acton
Wpilib Interface
Drivetrain
End Effector
Superstructure
Arm
Encoders
Exported Paths
Arm UI
Caching
Trajectory Following
Localizer (IMU Pi)
Joystick Reader
Autonomous
Vision
IMU
Exported Paths
Button Board
Pistol Grip
Spline UI
April Tag Detection
Vision PI
x4

April Tags - SLAM Mapping

- **Setup**
  - Vision processing runs individually on 4 rockpis
  - 30 Hz, 1280x720 pixel images
    - Logged to USB drive at full frequency (around 350 MB/s)

- **Mapping**
  - Solve for the location and orientation of april tags on a given field
  - This lets us account for imperfect placing of the tags

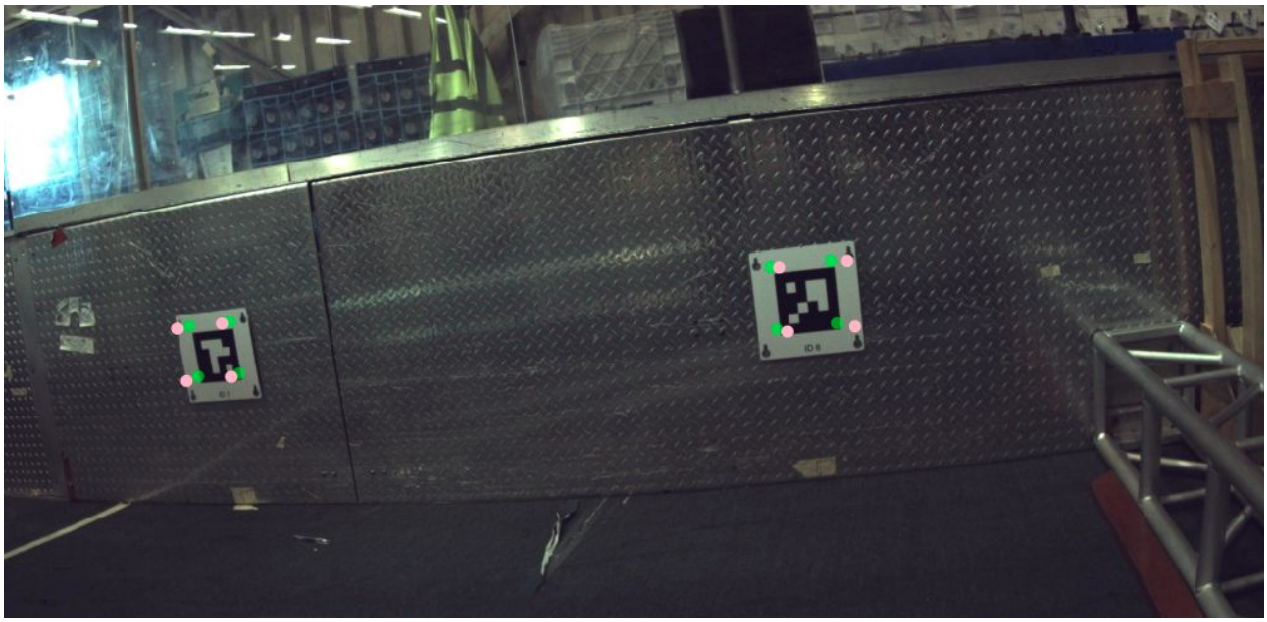
  - Process
    - Take a video of the tags with our box of pis
    - Stitch detections of different tags and from different cameras together
    - Solve for the relative locations of each target!
      - Using Google's Ceres auto-differentiating optimizer



971's Box of Pis

April Tags - Live Detection

- **April Detection**
  - Using aprilrobotics library from UMich
  - Filter noisy detections based on a variety of factors
    - Distortion effects
    - Pose estimation error
    - Brightness of the tag
  - Looking into parallelizing this process with Halide
- **Application**
  - Localizer (running on another rockpi) fuses data using an extended Kalman Filter to get an extremely accurate estimate of the robot's position and orientation, using:
    - Vision estimates from all 4 pis
    - IMU data
    - Drivetrain encoder readings
  - Robot pose estimate is used to auto-align the robot for placing game pieces, and to precisely follow paths in auto



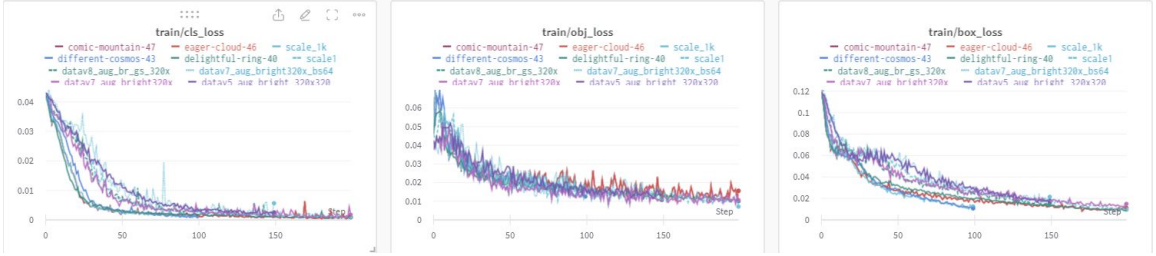
Live April Tag Detections

Game Piece Detection using Machine Learning

- **Training:**
  - Trained model using the YOLOv5 object detection model framework on a dataset of cone and cube images.
  - Our dataset consisted of a combination of real-world photos captured with a fisheye lens and synthetic game piece renders.
  - We utilized Weights and Biases to track, visualize, and compare various metrics across training runs.
  - To ensure high quality labeling and fast turnaround times, we took advantage of Scale AI's data labeling platform and services.
- **Inference:**
  - With the Coral USB Accelerator we were able to use it's Edge TPU coprocessor that provides hardware acceleration for fast and efficient object detection.

Model evaluation output

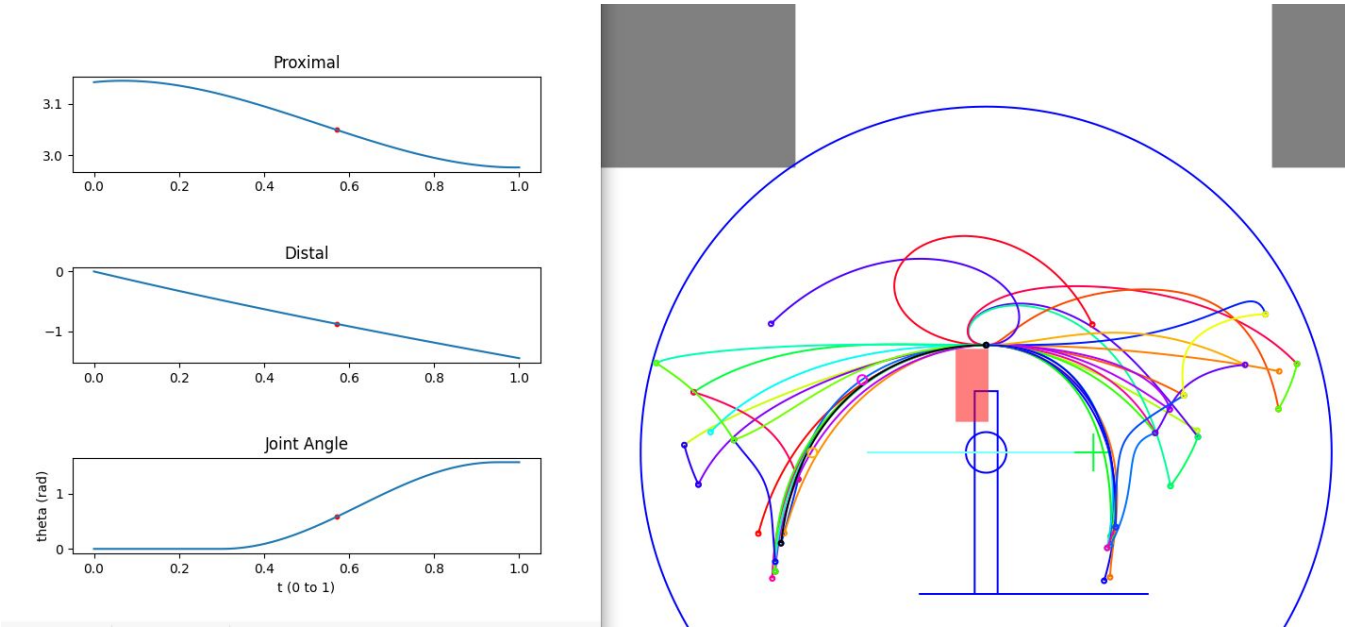
Coral USB Accelerator



Weights and Biases Training metrics

Arm Control

- **Arm UI**
  - Allows us to draw paths for our arm, controlling the proximal, distal, and roll joint
  - Checks for collisions between our end effector and driver camera
  - Generates fixed paths – the arm can ONLY follow these
- **Trajectory Following**
  - Trajectory following optimization done statically before we deploy to the robot
    - Computes the max accelerations and voltages throughout the path
  - Ensures that one of the joints isn't lagging behind the others – this would make us stray from the path and could cause a collision!
  - Proximal and distal states are estimated using one extended Kalman Filter, and roll joint is estimated in a separate filter



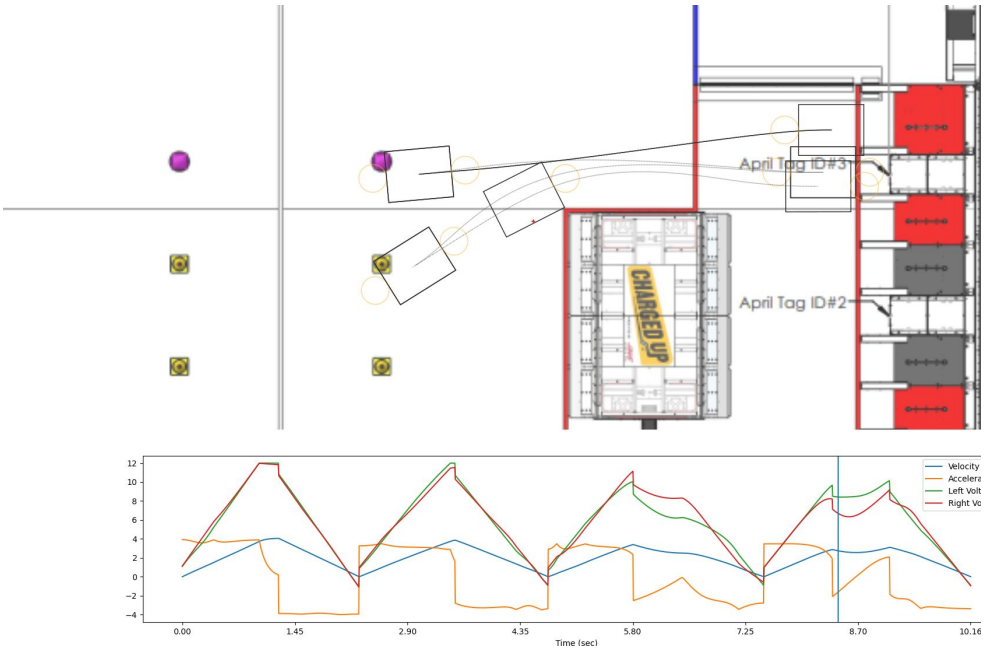
Arm UI

Autonomous

- **Spline UI**
  - Create paths that the robot follows during autonomous
  - Visualize how the robot will move along the paths and possible areas where it could collide
  - Stores the paths into json files which can then be read live on the robot
  - Contains information about voltage and acceleration to help pinpoint possible areas with a time loss

- **Autonomous Code**
  - Goes to the positions set using the paths and set the desired robot actions as the robot moves to the setpoints
  - Uses apriltag, IMU, and drivetrain encoder based localization to make sure that during auto we stay on the predefined paths
  - Uses arm paths specifically made for auto because we are certain that the robot will be in the exact position we need every time

Simultaneous movement of the drivetrain, arm, and end effector in the autonomous code allows the robot to pick up the game pieces efficiently and led us to have the best autonomous



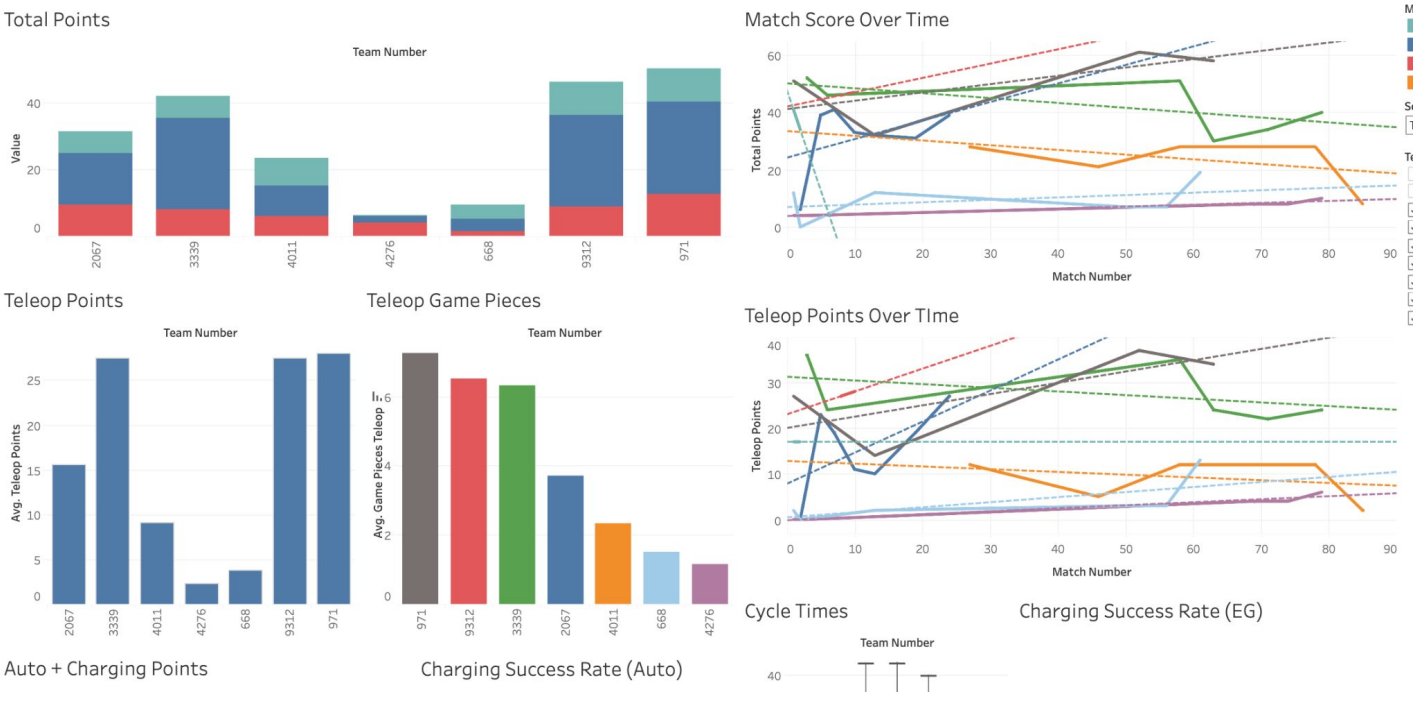
Spine UI

Competition

- Scouting
- Scouting App
- Drive practice

Scouting

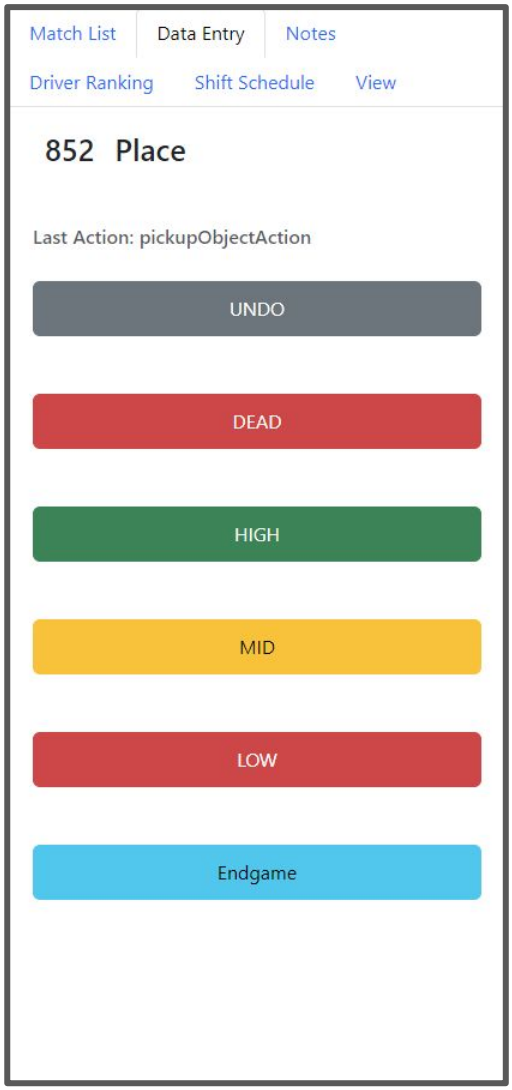
- **Simple, but mighty scouting interface**
  - Tracks cycle times based on when buttons are pressed
  - Simpler UI allows scouts to focus more on the game, and less on where to press
- **More people, more power**
  - Pairing up scouts to increase our data accuracy
    - Increasing student relations and allowing for more creative thought
    - Students are now more inclined to make observations about robots and tell their partner
  - Re-scouting
    - Always have an offline data scout on deck to make-up matches that were either missed or scouted incorrectly
      - Removes pressure associated with mistakes
- **See it in action**
  - All students can view all scouting data in tableau, and see how it is used to make informed choices in strategy and our picklist



Scouting App

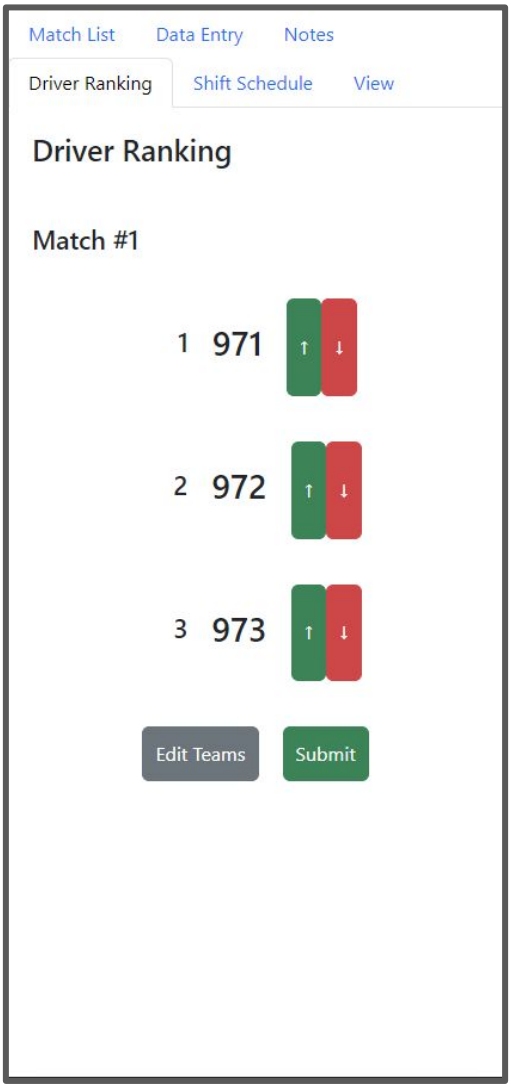
- **Overview**
  - 3 types of scouting (Data, Note, Driver Ranking)
  - Built with Angular, Typescript, Go, PostgreSQL, and Flatbuffers.

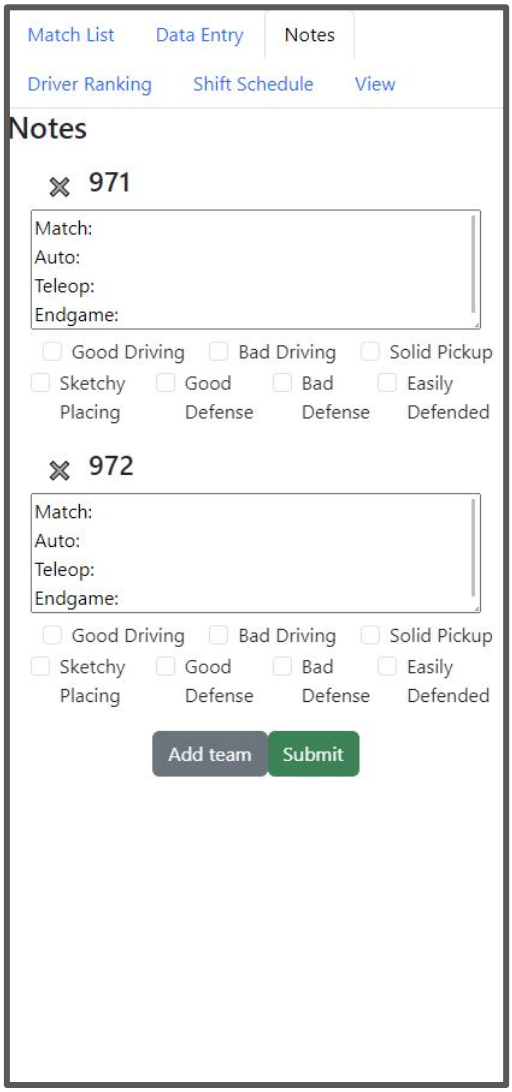
- **Data Scouting**
  - Quantitative robot evaluation
    - Measures cycle time, game pieces placed, balancing, etc.
  - A simple, condensed interface that only measures key metrics
    - Faster, easier scouting -> More accurate data
    - 96% data accuracy at Monterey Bay Regional



Scouting App

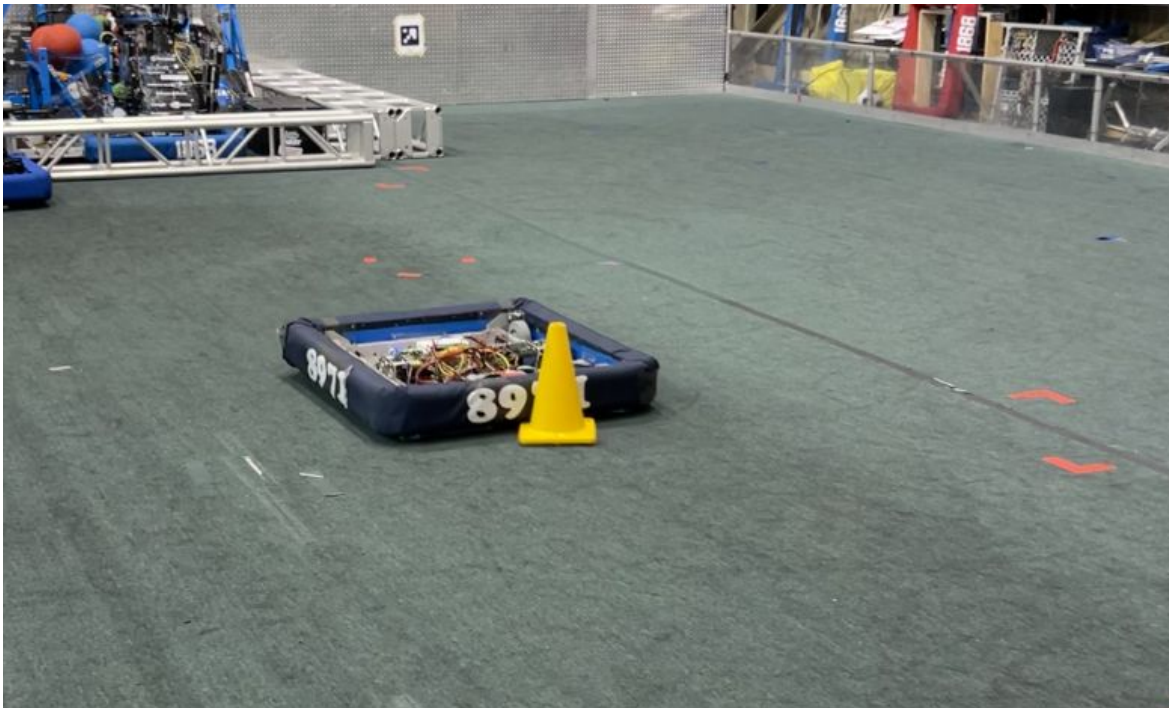
- **Note Scouting**
  - Qualitative, subjective robot evaluation
    - Ideas and information that cannot be expressed by just numbers
  - Keyboard shortcuts for efficient note-taking for multiple robots
  - Note template for more standardization
  - Keyword selection to sort notes faster and more effectively
- **Driver ranking**
  - Scouts subjectively rank driver ability within an alliance
  - A script then parses and calculates a final driver score that we use for picklist decisions.





Drive Practice

- **Main Goals**
  - Get 55 hours of drive practice
  - Practice in a variety of settings, with a variety of people
  - Get an early start
- **Kickoff-Week 0**
  - Used our 3rd robot drive base to get a feel for the game
  - Practiced pushing game pieces into nodes and across the field
  - Worked on maneuvers to avoid defense
  - **Results:**
    - Got our driver comfortable with the field before our robot was even built
    - Created a safety net that even if the robot broke, we would still have experience scoring
    - Gave our strategy team an idea of our approximate cycle time, and that crowding will be significant this season
    - Allowed us to put more time into training our operator



Drive Practice

- **Weeks 1-6**
  - Continued to fine-tune pathing with a new, faster robot
  - Focused on training our operator
    - Heavily on human player cycles
    - Updated our button board as more combinations came up, along with operator feedback
  - Emphasizing communication between our driver and operator
    - Practiced call-outs on and off the field
    - Attempted to re-create a competition environment to make sure they would be heard
  - CG control
    - Practiced how to create a balance between arm extension and acceleration to avoid tipping
    - Including a running bet between our lead competition mentor and our driver