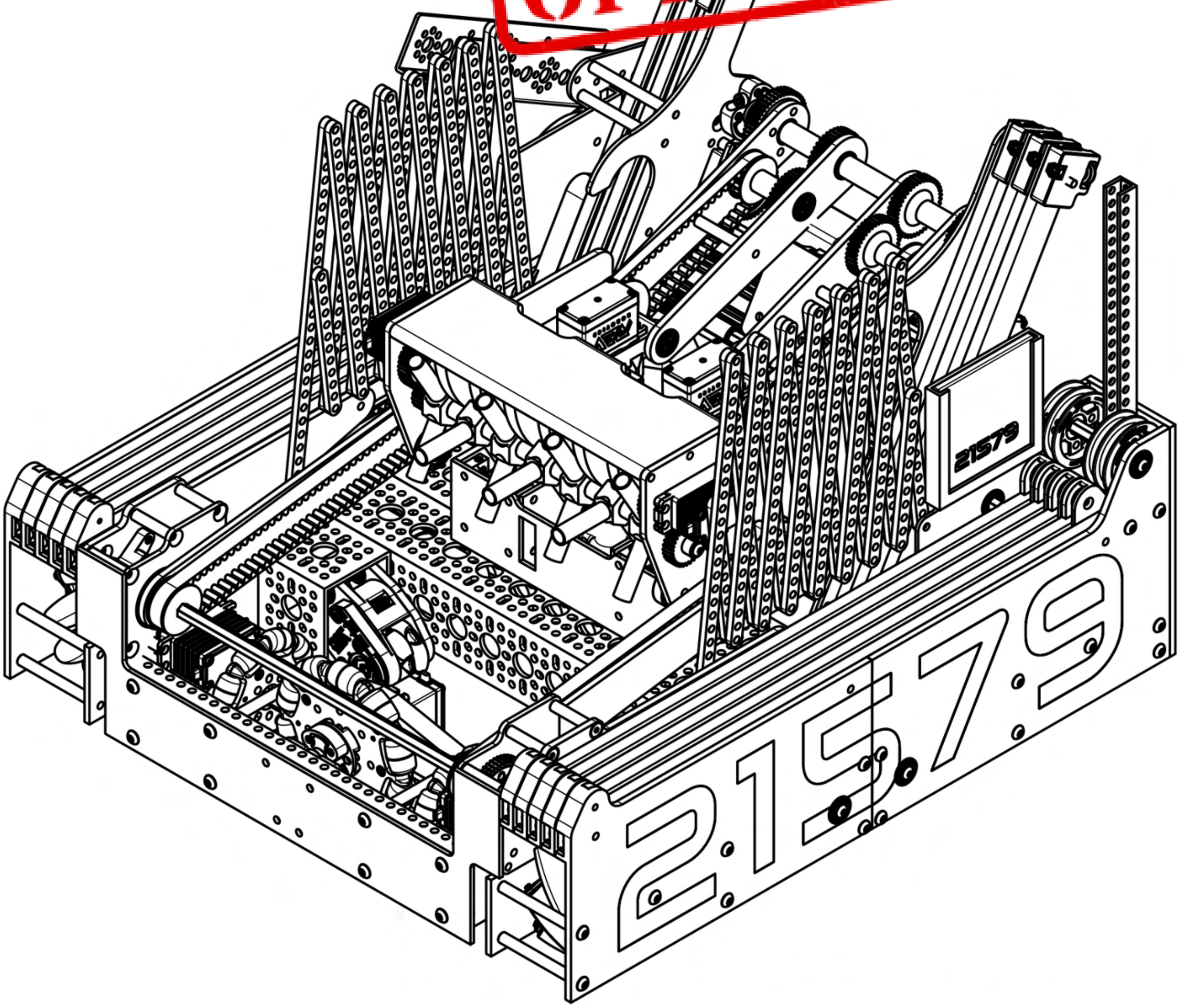
FTC #21579

TESTING IS OPTIONAL



NASA

PHANTOM SPACE CORPORATION

Raytheon Missiles & Defense

FIRST TECH CHALLENGE

SPIRITUAL GUARDIANS

Bulldog Ink Screenprinting, Embroidery, & More

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Introduction

FTC #21579
TESTING IS OPTIONAL

About Us

Testing is Optional, team 21579 is a FIRST® Tech Challenge robotics team community-based out of Tucson, Arizona. This season we have 3 adult mentors and 12 students, many are returning.

Our primary goals are to innovate and educate. We aim to innovate in hardware and software by using cutting-edge concepts and attempt to develop these concepts further. We strive to educate the students on our team and those in our community.

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Team Structure

To help facilitate proper project management and oversight, we use a team structure with a Team Captain as the full overseer, a “lead” for the Mechanical Team, Software Team, and the Outreach Team. Students are able to be a part of however many of these sub-teams as they want to best suit their interests and specialties. Each team lead is responsible for distributing tasks and managing projects appropriately and communicating with the other leads, as well as the Team Captain.

Images

Most of our images of mechanisms come straight out of Autodesk Fusion, real life, or are rendered using Blender. Using CAD software like Fusion is a great tool for designing and planning out complex systems like our bot. With the ability to create 3D models, we are able to see the intricate details of each subsystem and how they fit together, before even starting the physical building process. This not only saves time, but it also helps us to identify any potential clearance issues and make necessary adjustments before finalizing the design.

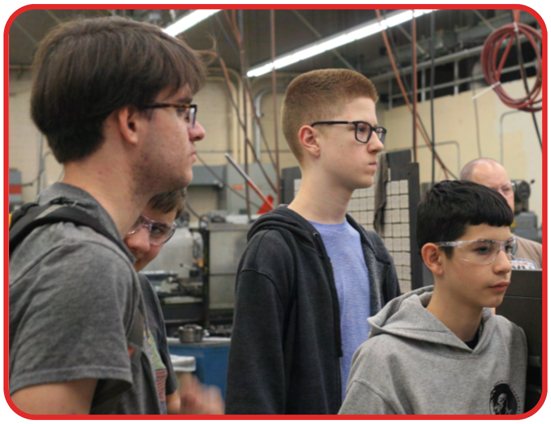
Sustainability

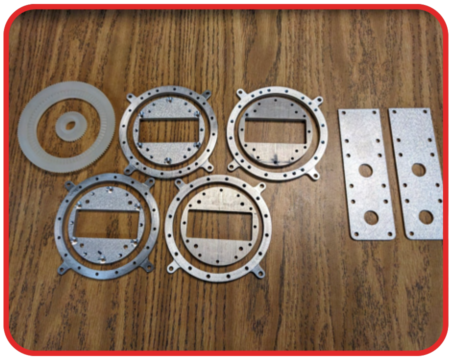
Having a team continue year after year is important. To help our team continue to compete, we help new members begin learning by giving them small projects and gradually growing the projects’ importance. The goal is to help build confidence in our members, so they learn something new along the way.

Technical Outreach

University of Arizona Machine Shop

This October we reached out to the University of Arizona and organized a tour of their machine shop facilities. The shop contributes to various university-based research projects, parts for NASA missions, and parts for various observatories across Arizona. **During this tour, we learned a valuable lesson: talk to a machinist about your design during the design process.**





NASA Machine Shop

During the development of our swerve drivetrain, we found the importance of having strong and rigid materials for the high-stress parts. To help combat the breaking of 3D printed parts, we **worked with NASA's Armstrong Flight Research Center to get stronger parts machined**. We had 10 parts made from aluminum, and 6 made from Nylon SLA printing.

Phantom Space Sponsorship

During the offseason we utilized an old connection from a tour in 2021 to reach out to Phantom Space Corporation and ask for a sponsorship. The CEO, Mr. Jim Cantrell responded and offered us the sponsorship. This was our first sponsorship of the season, which has **inspired us to reach out to more people and organizations** to help fund the team. So far we have **gained 3 new sponsors** since the end of last season.

Paragon Space Development Corp.

During the season two of our students went with one of our mentors to tour the facilities of Paragon Space Development Corporation with the CEO, Mr. Grant Anderson. We learned a lot about life systems in harsh environments, as this is their specialty. Seeing all the cool equipment and their awesome machine shop was super cool.

PHANTOM SPACE CORPORATION

PARAGON SPACE DEVELOPMENT CORPORATION

NASA

THE UNIVERSITY OF ARIZONA

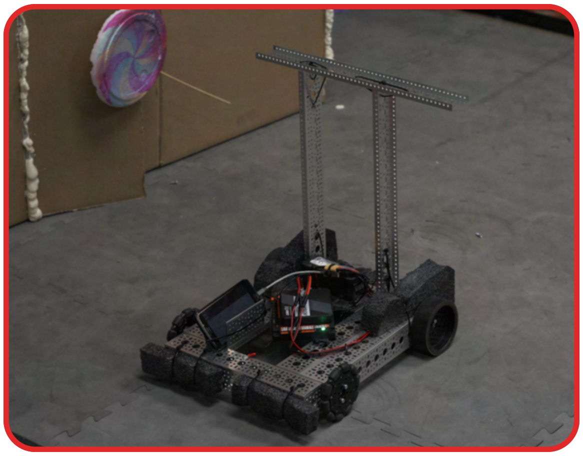
Outreach

Saddlebrooke Ranch

After the end of last season, we took our robot and a presentation with us to visit SaddleBrooke Ranch, a retirement community slightly north of Tucson. During our time there, we spoke to their technology club about FIRST, robotics, engineering in general, and our robot (with a fun demonstration of our PowerPlay robot). This was the first event that we planned as a team, and we learned a lot from the experience!

Back to Quest Night

In early September, our enrichment center hosted a “Back to Quest Night” themed *Candyland*. This night was a time for students to meet friends and learn about different on-campus teams and clubs, so we built a robot for anyone to drive around our Gingerbread House themed field. We also used our PowerPlay robot to hold a container of candy to give out to people around campus! **Our goal was to spark interest in our team and our FLL team, and possibly inspire people to join.**



Veteran’s Day with Spiritual Guardians

This season, our team was proud to partner with Spiritual Guardians, one of our valued sponsors, to show our appreciation for veterans at their annual event. We were dedicated to making a positive impact and **volunteered our time to distribute free food to veterans and collect donations to support Spiritual Guardians' mission**. We are grateful for the opportunity to give back to our community and support those who have served our country.

Operation Christmas Child

In the weeks leading up to Thanksgiving, our enrichment center was running an Operation Christmas Child fundraiser and donation drive. Operation Christmas Child is a Samaritan’s Purse project that collects shoeboxes filled with toys, school supplies, and personal care items that are delivered to children in need around the world. To support the cause, we **donated the proceeds of one of our fundraising events** to the drive, as well as contributed volunteers to help pack the boxes to be distributed.

Outreach

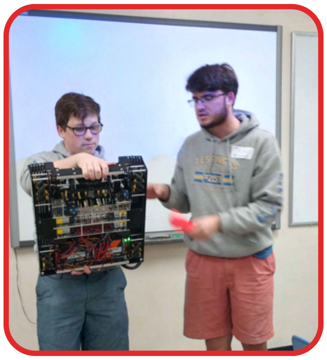
STEM Night

public release note: faces covered to protect privacy

To help spread STEM in our community, **we had a table at Harelson Elementary and Cross Middle School's joined STEM night**. At our table we had a 3D Printer to show the potential uses of 3D Printing and help spread the word about the technology. We also had our robot and a field setup throughout the night for a showcase that sparked lots of interest and questions about FIRST, our robot, and robotics in general! During the night, we also were networking with local STEM-related organizations and people, and are planning to help fix an attendee's CNC in the near future!

Software Feedback/Advice

In early February we were presented with an opportunity to receive feedback and advice from a Security Engineer at Notion (the productivity software company!) regarding our software library that we are collaborating on with FRC team 2141. We also **received advice on effective documenting, structuring, and testing for our robot's codebase**! The advice was super helpful and by implementing the strategies recommended, our code has become cleaner and worked with less iteration and testing!



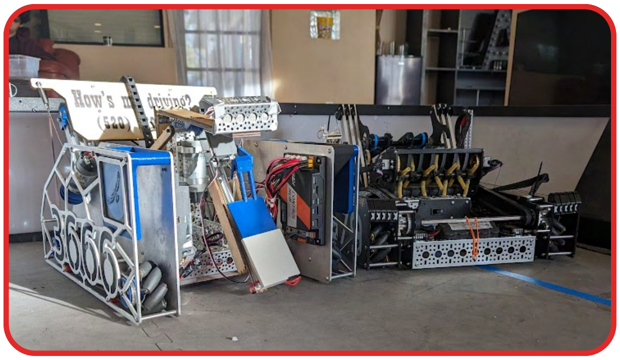
Presenting at PRCA

Starting in December we began to plan and organize a presentation for Pusch Ridge Christian Academy's High School Engineering class. The team **presented about FIRST and robotics**, but also **taught a class on the basics of programming Arduino**. Our goal with the time we were given was to spark interest in robotics and STEM, then follow through with giving the students somewhere to start their journey with robotics, electronics, and Arduino.

Other Initiatives

Throughout the season, we have had a few other initiatives, such as starting and **growing our social media presence** on Instagram (@testingisoptional) and Youtube (@ftc21579). We also have **donated time to the Feed My Starving Children** charity where we helped pack boxes of food to be distributed across the world. As a team, we have a fundraising initiative where we sell lunch to the students at our enrichment center. During this time we also try to raise awareness of the team.

FIRST Outreach



Scrimmages

So far this season, we have run two scrimmages with team 3666 *Hawks Robotics*. These scrimmages helped both of us collaborate and find the strengths and weaknesses in our robots. The events also helped us with find patterns in matches for driver practice. A lot of the time was also used to help each other fix robots.

Event Volunteering

This season we had two team members volunteer at the Tucson FIRST® LEGO® League Qualifier on December 2nd and the Copper FIRST® Tech Challenge Qualifier on February 3rd.

Collaboration

After kickoff, we started working with team 12869 - *Voyager 6+* from San Ramon, CA to collaborate on software techniques and **we learned a lot from a more experienced team**! We also collaborated with FRC team 2141 - *Spartonics* to develop a swerve drive kinematics and path following library, named quail. **This project has allowed us to gain worldwide reach** and assist teams from Lithuania (22042 - *Lithuanica X*) and Russia (9746 - *PML30 North Wind*) with swerve drive software, hardware, and documentation.

Team Assistance & Mentoring

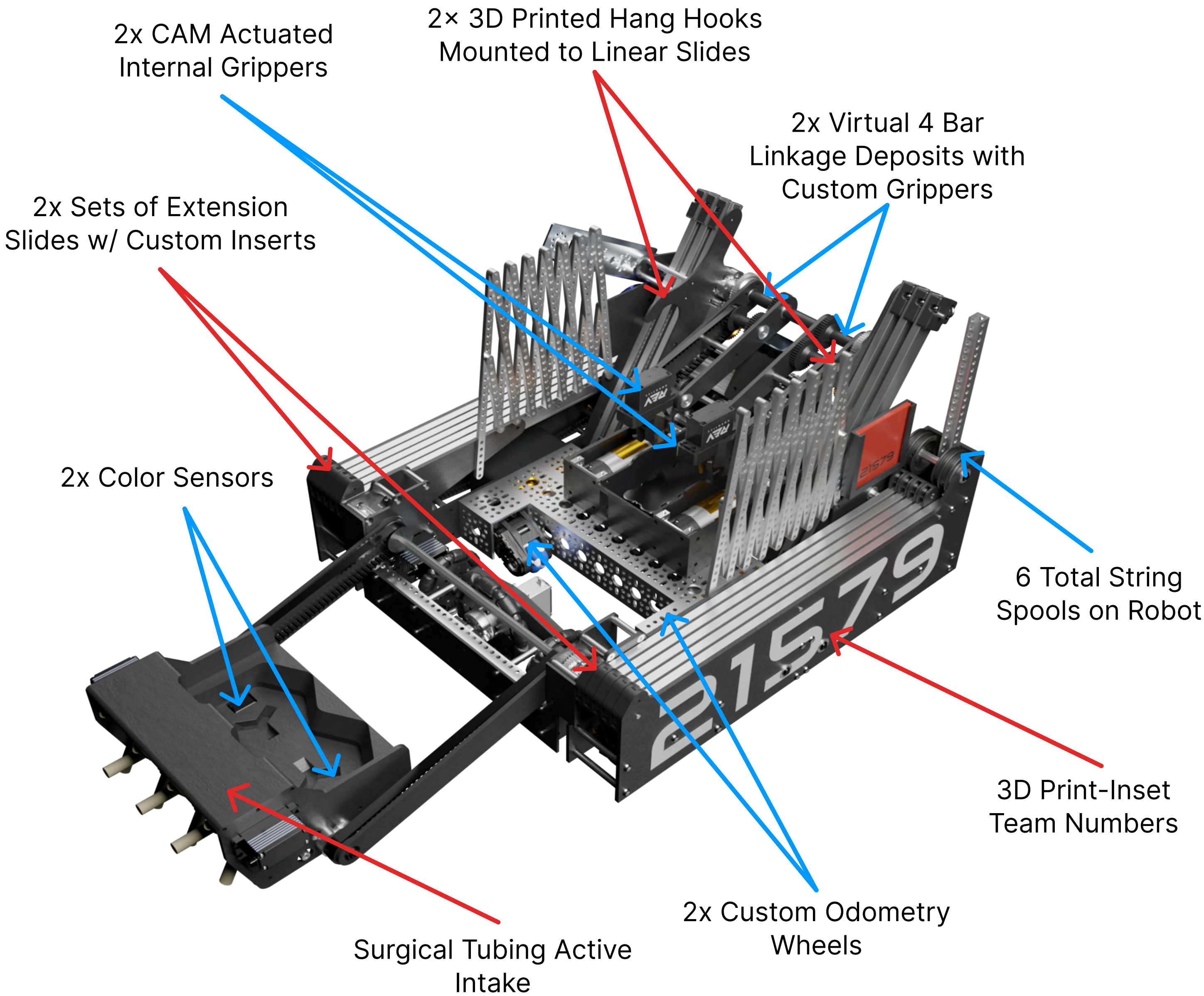
During the season and offseason, we have received software mentoring from FRC 2141 - *Spartonics* and received assistance from team 6547 - *Cobalt Colts*. We also made an effort to assist and mentor more teams, leading into mentoring a member from the Herberger teams (10111, 13968) on advanced mechanisms to help inform his team. In the late season we began mentoring team 18420 regarding the portfolio, general documentation, and judging. Utilizing the Unofficial FIRST Tech Challenge Discord server, we were **able to assist at least 20 teams, both US and International**, in hardware, software, and documentation.

1,750+ People Reached

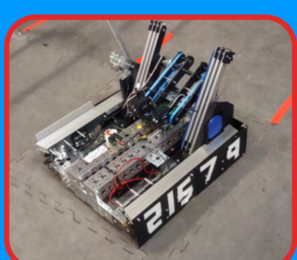
160+ Man Hours of Outreach

35+ quail downloads/month

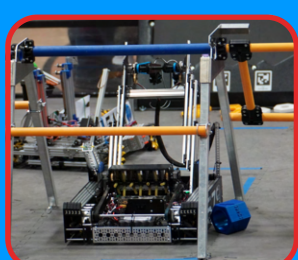
Bot Overview



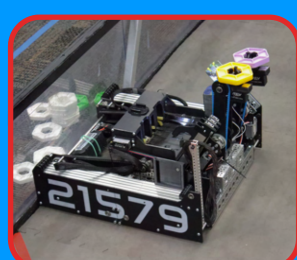
November



December



January



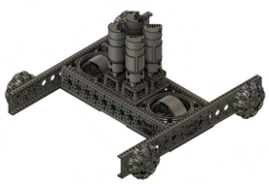
February

Differential Swerve

Why Differential Swerve?

Differential Swerve Drive is a highly complex system that has lots of failure points, so why did we choose to try it?

Like Mecanum, Swerve is holonomic, allowing the bot to travel in any direction with theoretically no turning radius. One of the key drawbacks to Mecanum is the lack of traction due to the rollers which can also affect speed. Swerve uses standard grip wheels, so both of these factors are removed, which is our primary reason for the drivetrain's use and development.

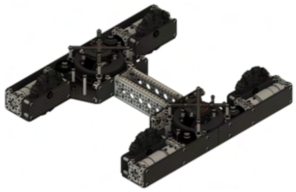


V1

Our first attempt at designing a differential swerve drivetrain. We attempted to use as many COTS goBILDA parts as possible. This prototype never left CAD and never got built.

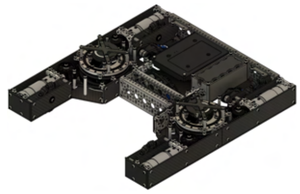
V2

We put together a single pod to test the design, and while it worked, it was clunky and the belts skipped a lot. Our physical version of the drivetrain lacked absolute encoders for the pods and we learned how important the encoders would be.



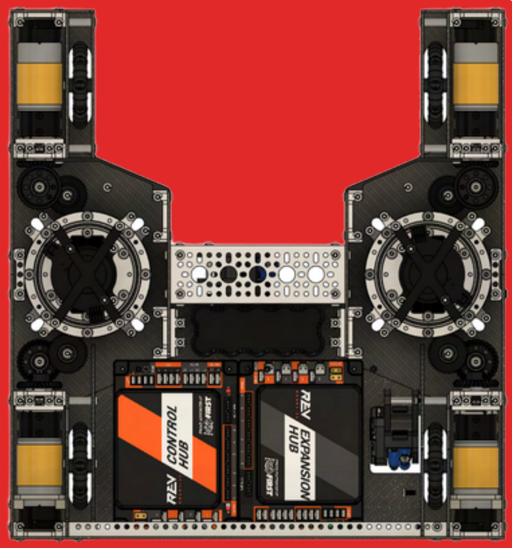
V3

The third version of our drivetrain moved away from using goBILDA structure and moved towards custom parts while remaining on the goBILDA pattern to make the addition of mechanisms significantly easier. This version continued with the skipping belts and holding the pods with V-Groove bearings.



V4

Moving into version four, we looked to reduce the friction in the pods. We moved to the use of X-Contact bearings, instead of the inefficient V-Groove bearings, and switched from belts to gears to reduce skipping. Absolute encoders were also put on the physical drivetrain during this stage of development.



Overview

2 Lamprey2 Encoders
2 Custom Odometry Pods
2 Custom Designed Wheels
4 goBILDA 1150 RPM Motors
4 3'5" X-Contact Bearings
42 Standoffs + Spacers
65 Custom Mechanical Parts + Plates
400+ Individual Screws

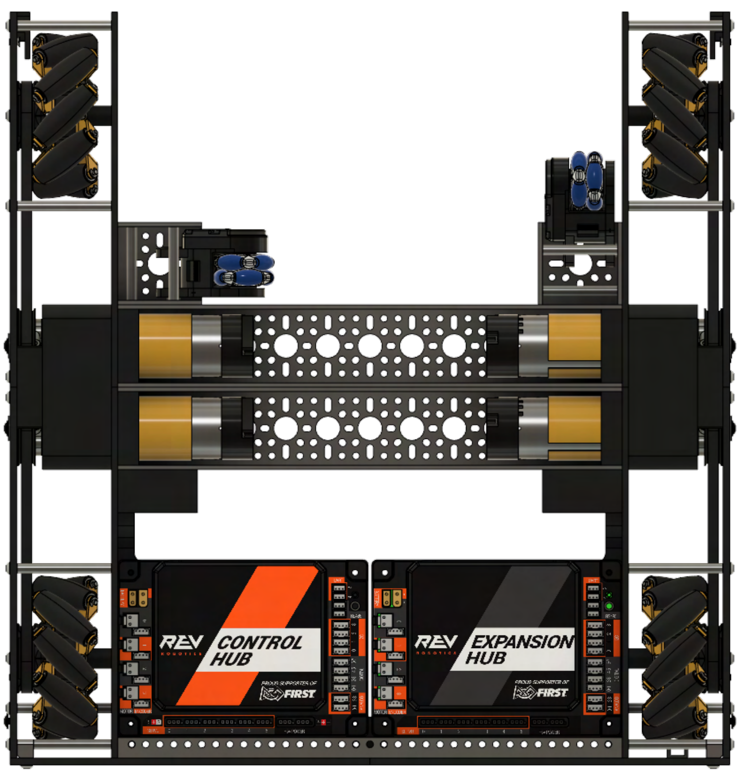
Mecanum Drivetrain

Completely Custom

For our drivetrain, we went with a **custom parallel plate mecanum** drive. Each wheel has a custom 3D-printed pulley mounted directly to the wheel hub. A dead axle running between the two parallel plates, which serves as the wheel's axle and structural support for the plates. A 312 RPM goBILDA yellowjacket motor drives each wheel via another custom 3D printed pulley and a 6mm wide HTD5 belt. Each side of the drivetrain is joined by 2 goBILDA aluminum channels and 1 goBILDA low-side aluminum channel to add structural rigidity.

By the Numbers:

1.5m/s maximum velocity
1.25m/s² maximum acceleration
1.5 Weeks of development
2 Custom Odometry Pods
4 Timing belts
4 Mecanum Wheels
16 Standoffs
20+ Custom 3D-Printed Parts
80+ Individual Screws



Custom Odometry

For localization during the autonomous period, we utilize **two sprung custom odometry pods**. Each pod consists of a REV through bore encoder, a 35mm omni-wheel, some bearings and hardware, and a custom housing to mount everything to.

Drivetrain Software

quail - Custom Swerve & Pathing Library

Due to the lack of pre-built libraries for handling autonomous and drive kinematics for differential swerve drives, we **collaborated with FRC Team 2141 - Spartonics to develop a software library** to handle this. We named it quail. The library handles swerve kinematics for both coaxial and differential swerve, as well as path followin

With the development of our pathing library came several challenges but came lots of customization. The path follower is under development, but is nearing competition-ready. It merges vector math and circle and line intersection for determining velocities and accelerations. This method is similar to two popular algorithms: Guiding Vector Fields (GVF) and Pure Pursuit in that the algorithm utilizes feedback from the robot's localization/position to recover after contact or unexpected movements.

For the bot to know where it is on the field, we needed a form of the localizer, so we created a **custom two-dead wheel (odometry) localizer** for quail. Using two dead wheels does not provide enough information to localize, so we use the control hub IMU to read the robot's heading. When this code is combined with our hardware, we can achieve **within ~0.1 inches of the accuracy** of translation.

Field Centric Drive

Our drivers have the **option to use field-centric** (pushing forwards on the joystick always goes the same way) **or robot-centric** (like a car) driving. The driver is able to choose based on their liking, and even switch while driving to help adapt to different situations on the field. We utilize the IMU in the Control Hub and the equations below for field-centric driving.

$$y_2 = x_1 sin\beta + y_1 cos\beta$$

$$x_2 = x_1 cos\beta - y_1 sin\beta$$

Localization Math

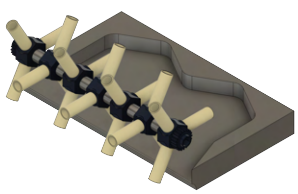
x_1 and y_1 represent the updated/new coordinates of the rbot, x_0 and y_0 represent the previous position of the bot, Θ_0 represents the previous heading of the bot from the IMU. Δx and Δy are the change in position of the bot according to the parallel and lateral deadwheels.

$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} + \begin{bmatrix} cos\theta_0 & -sin\theta_0 \\ sin\theta_0 & cos\theta_0 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

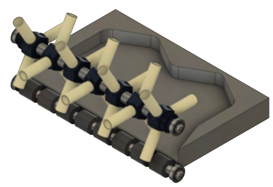
Intake + Extension

Intake

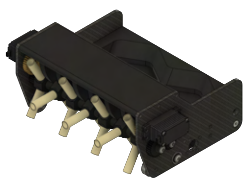
To solve this season's challenge of scoring pixels, we decided that an **active intake would perform quicker and more reliably compared to a claw**-like passive intake. Our intake uses 1/4" surgical tubing mounted on custom 3D-printed inserts. Underneath the main intake shaft is a separate counter-roller which spins in the opposite direction of the main intake spinner. This helps pixels get off the ground and into our intake hopper. The intake and counter-roller are powered by an Axon Mini+ servo on each side geared up 2:1 for more speed.



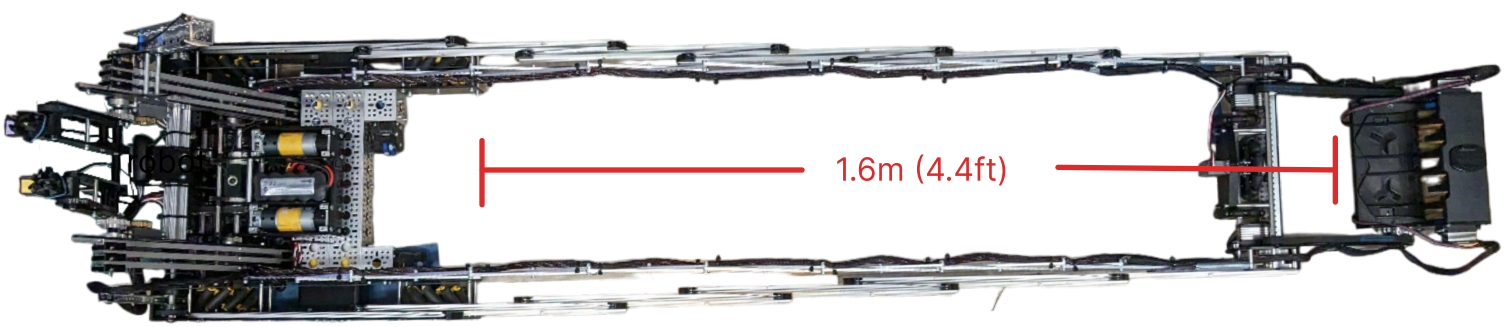
V1: Unable to lift pixels off the floor



V2: Pixels fly out the top/ front



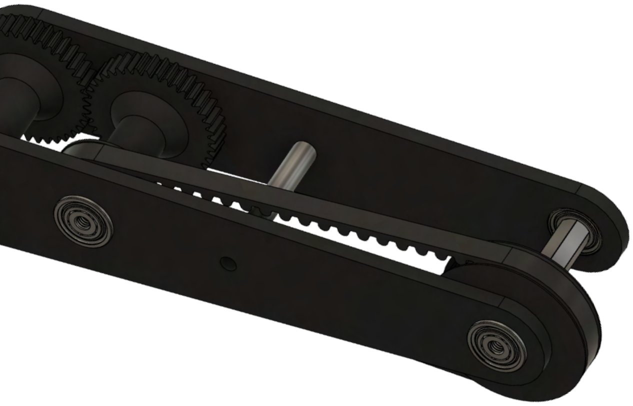
V3: Spinner is not strong enough



Extension Slides

Early on in the season we decided to **mount our entire intake subsystem to a horizontal extension to decrease our cycle times**. Originally, these extension slides were designed to be driven by a scissor linkage, but we soon discovered that the linkages had way too much play in them to be a viable way to extend and retract the slides. Currently we still have the linkages on the robot but they are unpowered and are used for cable management. The horizontal extension consists of 2 sets of 5 stages of Misumi SAR240 Linear Slides, which gives us about **1.6m (4.4ft) of total robot extension**. The slides are continuously strung with custom bearing inserts and are driven by 35mm pulleys. The actuation of the pulleys can be read about on page 12.

Deposit Arms + Lift

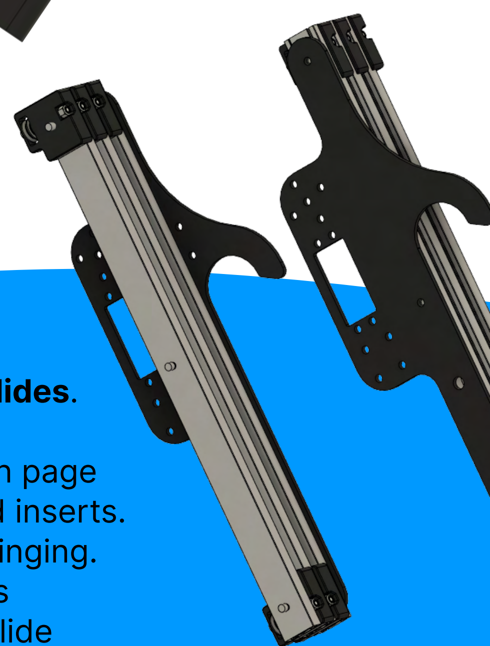


Virtual 4 Bar Linkage Arms

To bring the pixels from the transfer (down) position to the deposit (up) position, we utilize **dual individually actuated virtual 4 bars**. These are driven using goBILDA Torque Servos and operate similarly to the intake's V4B, except instead of a 1:1 pulley ratio, a 3:2 ratio is used to allow the pixels to be at a 90-degree angle at the transfer position, but a 30-degree angle at the deposit position to match the backdrop.

Internal Grippers

To grip the pixels and then release them on command, we use a **cam-actuated internal gripper**. Each claw has a servo with a **custom-designed cam to actuate** all **three internal hooks** from a range of 0 to 15 degrees. A rubber band is used to force the hooks to always be in contact with the cam. Each hook is shaped like an arrow which acts as both a guide and a latch to securely lock onto the pixels when transferring.

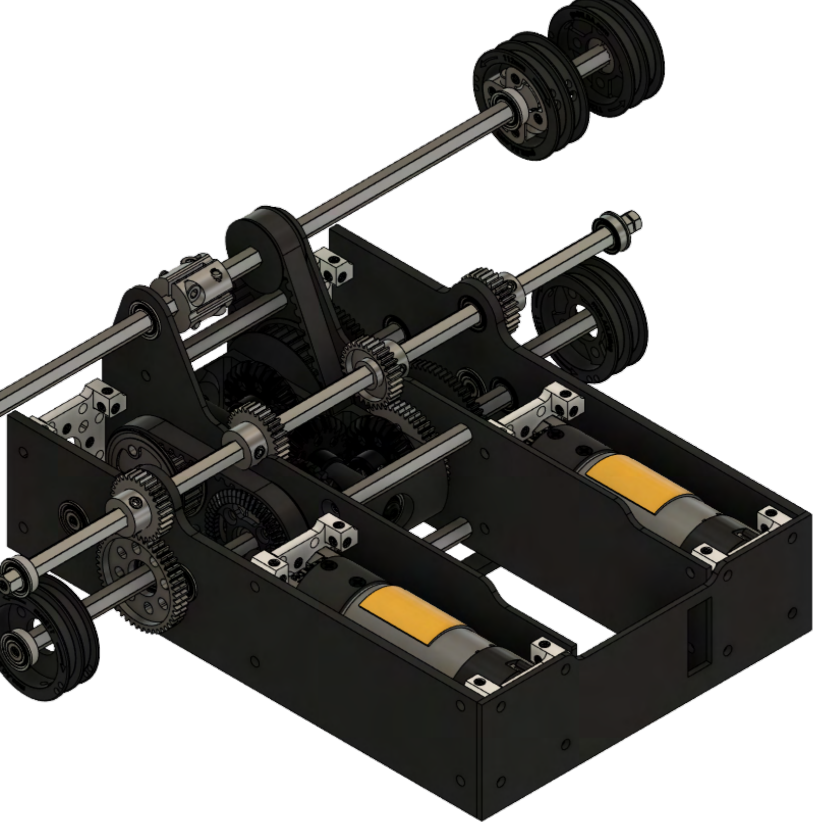


Lifting and Hanging

Our lift is **comprised of 2 sets of 3 stages of Misumi SAR230 Linear Slides**. These slides are driven by a 35mm pulley for each set. The pulleys are powered by the differential power take off system explained in detail on page 12. To connect the individual slide stages, we utilize custom 3D-printed inserts. These also hold the v-groove bearings allowing for continuous type stringing. Our **lift doubles as our hanging mechanism** during Endgame. A hook is integrated into the custom 3D-printed plate on the last stage of each slide assembly.

Mounted Drone Launcher

To help with scoring consistency, we found that placing the drone launcher mechanism on our lift was more effective than having the launcher fixed to the drivetrain. This makes it easier to launch over the truss, as the drone starts above the truss.



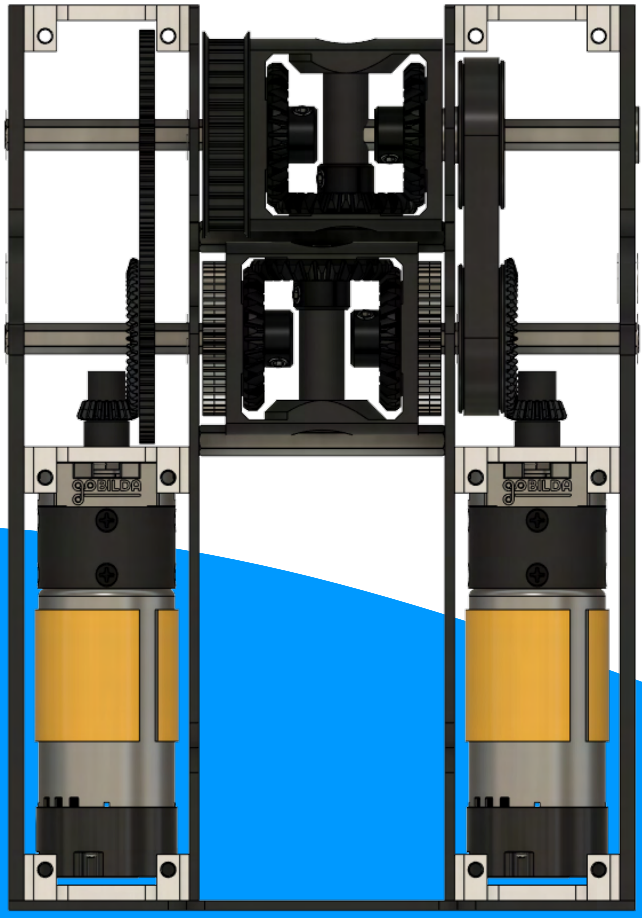
Power Take-Off

Differential PTO, Why?

To power our horizontal and vertical extensions, we had an issue with the packaging and weight of four motors which would normally be needed. Our robot was 30lbs before adding the extra two motors for the horizontal extension. To help counter this **we decided to use a Differential Power Take Off, meaning we can use only two motors for two different subsystems** while retaining the greater amount of torque and speed from the pair of motors. This is especially helpful for hanging with the lift, as it requires a lot of strength to do.

How Does it Work?

The way the system works is by **utilizing two separate differentials**. They do what they sound like, they take the difference between two inputs and create an output. The rotatio**n of the two differential casings are the outputs for each set of slides**. To have different outputs, the differentials are coupled together by gears on one side and a belt on the other. Spinning the motors in the same direction controls the rear differential (the extension) and spinning the motors in opposite directions spins the near differential (the lift).



Kinematic Equations

To calculate the motor speeds for each motor based on our target velocities and given gear ratios, we use the equation below. *R* represents a ratio, *V* represents a velocity, *L* represents the lift, *E* represents the extension.

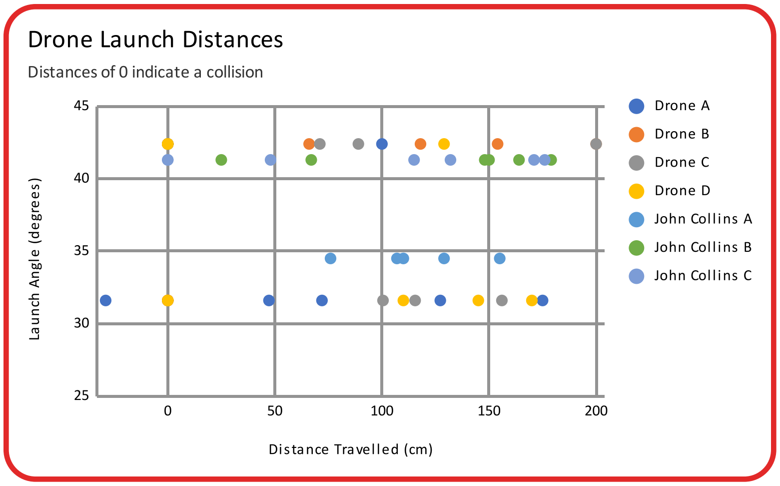
$$V_{m1} = \frac{R_L V_L + R_E V_E}{2}$$

$$V_{m2} = \frac{R_L V_L - R_E V_E}{2}$$

Drone

Drone Design

The drone has been quite the challenge for us this season. During our qualifiers, we scored a total of 0 points with the drone. This has been due to a mix of reasons, partly due to the lack of time to properly implement and also partly due to the rubber band not having a consistent stored energy. This combined with finding the best design for the drone itself has been tough.

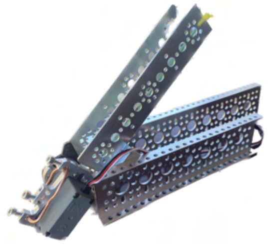


Research on Drone Designs

We had a team of three people set off to work on our design for the drone. The first step taken was to do research, where the team found the **world record paper airplane by distance**, designed by John Collins. We found this design to fly well and made modifications to fit our robot best. The main modification was **adjusting the wingspan to prevent the drone's wings from colliding with the lift.**

Data Analysis

To help use test drone designs and ensure that we get the design that is the most consistent at traveling the distance we want, we took measurements for multiple launches of each of our primary design ideas and graphed them to find a consistently flying design.



Launcher Design

Our drone launcher utilizes a single Tetrix U-Channel for the guide/channel that holds the drone. We noticed that drones tend to fall out during matches, so we added a zip-tie to the top to prevent the drone from bouncing out. For the launching of the drone, **we utilize stored potential energy in the form of a rubber band**. The rubber band gets released using a small servo horn mounted to a servo.

State Machines

The entirety of our bot runs on a **full-bot Finite State Machine** (FSM) with four primary states, Intake, Transfer, Deposit, and Endgame. Each subsystem also has a state machine for controlling the various functions of the system. The Intake V4B, Intake Spinner, Drone Launcher, Deposit V4B, and Deposit Gripper subsystems all use FSMs, while the Deposit Lift and Intake Extension uses a standard state machine, meaning it has a non-finite number of states due to the manually controlled nature of the subsystem. The Intake state's primary objective is to intake pixels into the robot, the Transfer state is an intermediary state for travel that serves as a reset point and also the point for the robot to transfer pixels from the intake to the deposit. The Deposit state allows for the depositing of pixels into the backstage or backdrop depending on driver input. The Endgame state introduces the control of the Drone Launcher subsystem and unique controls to efficiently suspend from the Rigging. To help manage all of these state machines and subsystems, **we utilize FTCLib's command structure**. Using commands helps us more rapidly create sequences of events in TeleOp and in Autonomous. It is possible for the driver to **get to any robot state within 2 button presses** because of the command system.

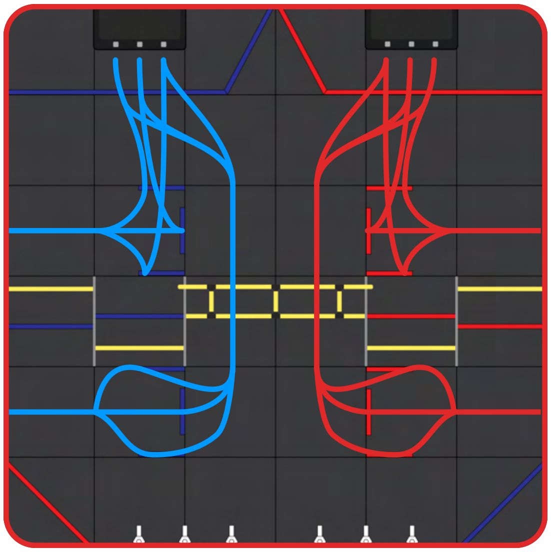
Closing the Loop

This season we focused on implementing "closed-loop" control as much as possible. This means that as much as possible, we use feedback from systems (utilizing various sensors) and adapt our control of those systems based on the feedback, a good example of this is PID. We also adapt our heading mechanism dependent on the position of the extension slides to help prevent slippage on the field and prevent adding extra stress on the extension slides. **Having closed loop control is essential for us to ensure that each subsystem is behaving as intended and to prevent damage to the robot.**

Kinematic Control

Our robot employs multiple complex systems that require **mathematics to determine the current state and behavior of the system and equations for determining motor powers to achieve specific behaviors** and outputs. These equations have been present throughout the portfolio on the page with the subsystem, and we derive all the equations and implement them by hand using testing code before implementing them into the full codebase.

Autonomous + Automations

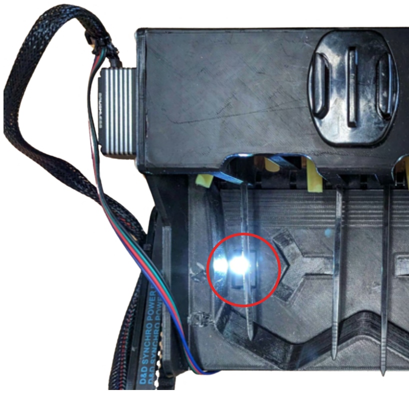


Autonomous Objectives

During the autonomous period, we utilize a **custom EasyOpenCV vision pipeline to detect the team prop**'s randomization. We then use this information to place the purple and the yellow pixels in the appropriate location. During match setup, we allow our drivers to select a **configurable parking location** (left or right of the backdrop) and a **configurable start delay** to help reduce potential collisions and interference with our alliance partner. We also have the option to attempt to take extra pixels off the pixel stacks on the audience side wall. Due to the inconsistency of this path, we made it optional. For all movement we utilize the Roadrunner library.

Multiple TeleOp Automations

During driver control, we utilize sensors and state machines to create various automations. Our favorite automation is an **automatic transfer using the color sensors** present inside the intake hopper that holds pixels. Once two pixels are detect, the robot automatically transfers the pixels. We also utilize an analog distance sensor on the back side of the robot to help with distance alignment with the backdrop to reduce error and reduce the potential to knock pixels off the backdrop.



Emphasis on Driver Feedback

The high complexity of the robot makes it hard for the drivers to tell what is going on with the robot, so we **enlist controller vibrations** and **LEDs** on the robot and on the driver controllers to provide feedback. The vibrations are used to indicate how many pixels are properly in the intake and which side they of the intake they are on, and the LEDs are used to relay robot state information to the drivers in general, and more specific use cases during various actions.