# SCRAP METAL
# ENGINEERING PORTFOLIO

"BUILDING OK ROBOTS SINCE '21"

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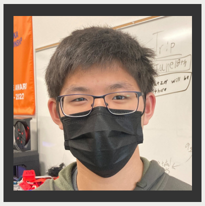
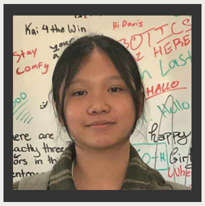
# MEET THE TEAM!

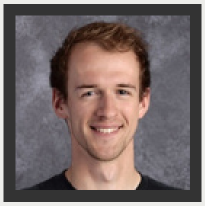


**Manning – Programmer**
Hey, I'm Manning. For my 9th year of FIRST, I'm excited to mentor the new members of our club in programming! I love spreading my knowledge to others, and I hope to become a better teacher as the season goes on. In my free time, I like messing around with control theory, Linux, and unicycling.

**Iuli – Builder and Designer**
My name is Iuli, this is my 8th year of FIRST, 2nd year of FTC, and first year on Scrap Metal. I mainly focus on the design of our robot, but also love having the opportunity to push my limits as a designer, and share my knowledge with newer members of the club. Outside of robotics I love hiking, climbing, backcountry skiing, and anything else outdoors!

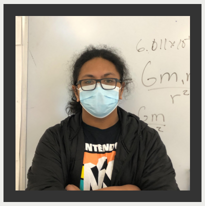


**Luci – Builder**
Hai! My name is Luci. I am a sophomore and this is my second year in robotics. I have always been interested in programming and building which is why I started learning both and I am enjoying it! I am very excited to continue my journey and be a part of this club!



**Mr. Troll – Team Coach**
Mr. Troll has been at West High teaching math since 2015 and coaching robotics since 2019. As a coach with minimal robotics skills, his leadership role can best be defined as a spirited motivator, cunning recruiter, and "school employee supervisor". Through his coaching, he hopes to inspire his students to successful futures as problem solvers and STEM professionals.

**Toa – Builder and Designer**
Hello, my name is Toa and my main role on the team is to help build and design the robot. I got into robotics in elementary doing FLL. I'm excited to be in my 3nd year of FTC and 5th year of FIRST. Outside of robotics I like to play video games or learn interesting things within STEM.



**Grace – Electrician and Builder**
Hi, I'm Grace. I am a junior and it is my first year of FTC and FIRST. I have always been interested in building and found West High Robotics as a second home full of like minded individuals. I am an eager learner for all things robotics and soon to become a programmer.

**Seventh Wheel – Robot**
I am Seventh Wheel, son of Fifth Wheel, harbinger of late nights, and consumer of zip ties. This season, I am excited to drive fast, munch up pixels, and brown out my battery in less than 10 minutes of driving! Outside of competitions I enjoy being pushed around in carts, and breaking the backs of my creators when they can't seem to find one.

**Maxim – Assistant Coach**
Howdy, my name is Maxim. I'm a former West Robotics alumni, and since I'm going to school at UAA I get to be the assistant coach and give back to the club. Apart from robotics, I like to go garage-saling for old technology.

# Team Plan

## Sustainability

- Keep team alive
  - Stay small, 5 person team
    - More fun + each person has more opportunities to learn and shape the robot
    - More personal connections with team members
    - Older members mentor new members
    - 1-2 new members each year
- Build on past experience
  - End goal: write up all of our knowledge and lessons learned into a reference for all future members

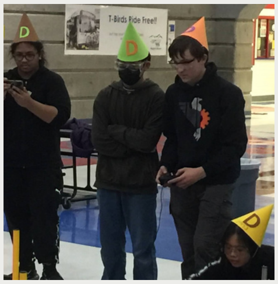
## Team Budget

Our expenses and deposits are tracked in a spreadsheet, which makes it easy to tabulate how much more money we need to raise to buy desired parts.

| 19953 | Balance: | $72.29 |
|---|---|---|
| **transaction** | **deposit** | **expense** |
| initial balance | $200.00 | |
| orange card sale | $20.00 | |
| donation | $5.00 | |
| oc sales (9/25 | $140.00 | |
| REV, ServoCity, Amazon order (9 | | $63.79 |
| Misumi(10/13) | | $234.65 |
| McMaster(10/13) | | $41.16 |
| gobilda order (10/16) | | $128.96 |
| axon (11/2 | | $242.92 |
| sc (11/15) | | $336.35 |
| cash donation 1 | $250.00 | |
| RD donation | $400.00 | |
| spc cash donaio | $60.00 | |
| oc sales (11/28) | $20.00 | |
| rt sales (11/28) | $50.00 | |
| amzn (12/1) | | $24.89 |

## Team Identity

We embody the idea of **Scrap Metal**: we aren't afraid to experiment, or create something that looks jank, ugly, wacky, and made of scrap metal. If we mess up along the way, it's okay as long as we come out better in the end.



*Team tradition: we always wear colorful dunce caps to all our competitions*

## Season Goals

- Qualify for worlds
- Have a cycle time from backdrop to backdrop of less than 8 seconds
  - **Achieved!** Average cycles are 8 seconds, and can be as fast as 6.5 seconds
- Score at least 4 additional pixels after the preload in auto
  - 2 Additional pixels have been scored
- Fully test the robot before competitions
- Give at least 15 presentations to different STEM classes to increase interest in STEM, FIRST, and robotics
  - **Achieved!** (pg. 4)
- Connect with the local technical community to learn more about how FTC skills can be applied in the professional world
  - **Achieved!** (pg.5)

## Design Principles

- "CAD it out"
  - Our team uses Fusion 360 to CAD out as much of the robot as we can
  - Ideas are tested in CAD, prototyped, and integrated into the bot
- "Field-test it!"
  - Mechanisms need to be tested and prototyped before time is spent finalizing the CAD design
  - Prototypes are deemed ready to proceed when they **almost never** fail, >97% success rate
- "Always put 4 screws"
  - Even when prototyping, use 4 screws as the prototype might end up staying on the competition robot
- "Save the software!"
  - During crunch time before competition software often gets pushed to the side in favor of fixing mechanical issues
  - We set specific deadlines by which the robot must be ready for software testing, and maintain constant communication between our hardware and software teams so our robot can have great software as well as hardware

# CLUB PLAN


## Season Goals

- Reach out to at least 4 local businesses
  - Cover additional expenses of having 4 teams in a single club
    - Achieved! We contacted 8 independent business while fundraising
    - Achieved! Club balance of almost $4,000
  - Show new teams how to fundraise
- Qualify all teams to state

## Sustainability

- Continue to grow the West High Robotics Club: size and awareness in school
- 10 new active members
- Aggressive advertising
  - Freshman Congress
  - Freshman Fair
- Train new members
  - Provide outreach opportunities for new members for more club involvement
  - Pass down obscure knowledge learned the hard way
  - Provide information without providing the answers

## Fundraising

- Club Fundraising
  - Recurring club sponsors and West High Alumni Foundation provide funds for registration
- Team Fundraising
  - Normally not needed, but our costly rebuild plans required extra fundraising efforts
  - Contacted STEM companies who could supply money, materials, or parts
    - PND Engineers
    - RESPEC
    - Metal Supermarkets
    - Image Plastics
    - O'Reilly Auto Parts
    - Napa Auto Parts
    - Autozone
    - AIH

## Sponsors:

Benthic GeoScience
Support907 Alaska
Loken Construction, LLC Anchorage, Alaska
70°N
Alaska Air Transit
Resource Data
Metal supermarkets
PND Engineers, Inc.

# COMMUNITY OUTREACH

## Mission

Our team's community outreach is primarily focused on elementary and middle school age kids, with a strong focus on inspiration and the spreading of STEM. There is no better feeling than when a class of kids gets excited about driving a robot, and we are thankful to have the opportunity to spread STEM and FIRST robotics as much as possible. During outreach events we aim to **inspire** by allowing kids to drive our robot and get excited about STEM, **inform** children, parents, and teachers of opportunities that are available for kids interested in STEM, and **connect** with the kids by pointing out links between the skills they are developing and the robots we build.

## STEM Nights

**Inspire**, **Inform**

Demoing our robot to kids and parents at elementary school STEM/STEAM nights

- Turnagain Elementary
- Bear Valley
- Willow Crest
- Lake Hood

## School Presentations

**Inspire**, **Connect**

Longer presentations and demos with STEM classes to provide an in-depth look into FTC

- Waldorf
  - We brought practice bots, FTC robot sets that the kids were able to assemble and get a hands on learning experience
- Campbell
- Romig x5
- Central x2

## FLL Competitions

**Connect**

Volunteering at FLL competitions to give back to the FIRST community and provide information on FTC to interested FLL members

12/02/23 - FLL Qualifier

12/16/23 - FLL Qualifier - Toa received the volunteer award!

01/28/24 - FLL State

## Other Outreach

STEM Week Presentations

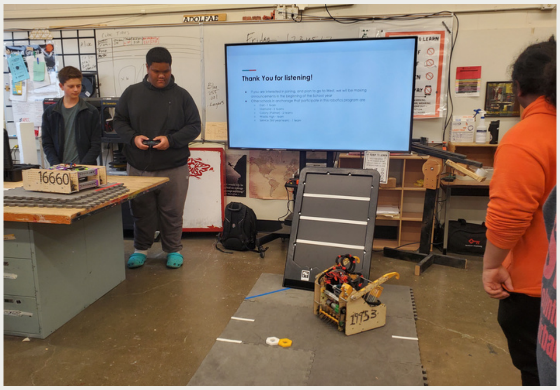
- **Inform**
- Presented about West High Robotics to a large number of math, science, and technology classes during West High's STEM week

Alaska Museum

- **Inspire**, **Inform**
- Presented our robot at a booth at a STEM event at the Alaska Museum of Science and Nature
- Partnered with FRC team 568

State Fair

- **Inspire**, **Inform**
- Setup our Powerplay robot and field in the STEM tent at the state fair and allowed visitors to drive the robot




◆ **500+ Kids Impacted**
(excluding FLL competitions)

◆ **100+ Hours**

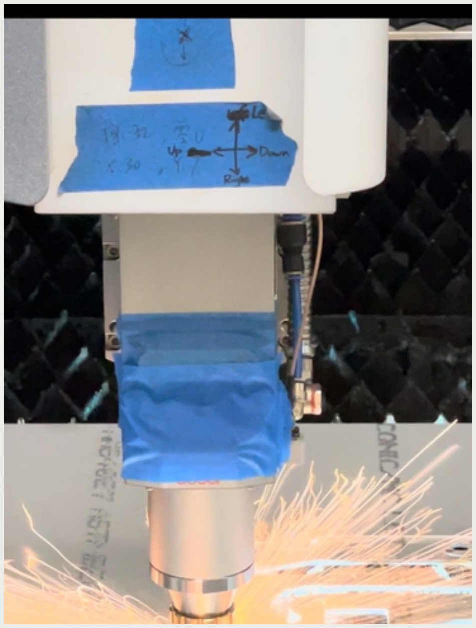
# TECHNICAL OUTREACH

## Mission

This season we wanted to expand our technical outreach and accomplish three main goals: introduce FIRST and the opportunities it provides to a larger audience, learn more about how the skills we develop in FTC can be applied professionally, and gain input and advice on our robot from industry professionals.

## Metal Supermarkets

To facilitate the use of aluminum on our V2 we contacted Metal Supermarkets, a local business that specializes in metal supply and fabrication. They gave us access to their high power laser cutter as well as a materials budget for the season. They also provided useful advice in their area of expertise, giving us advice on material thickness, pocketing, and metal type. An example of this was when they were cutting our custom sprockets, after the first batch Terry, the owner, requested that they be recut with nitrogen instead of oxygen, which resulted in a cleaner cut and positively impacted performance of our hang.



## PND Engineers Inc.

We contacted PND Engineers, a local AK based engineering firm. They agreed to let us present to members of their engineering team, and we were able to demonstrate our robot, as well as discuss our future plans. We discussed the importance of STEM skills and their uses in an engineering career.

## RESPEC

RESPEC is an IT company that specializes in engineering, programming, and problem solving. We presented our robot and plan for improvement to them, and some of the employees were so impressed they gave the team personal donations. We also communicated with many of the staff, who were previously involved in FIRST programs.

## Resource Data

For the past 2 years we have partnered with Resource Data, a local software development company. After coordination with sister West High team 16660, they agreed to send some of their GIS software developers to present to our first period AP Computer Science class, which is attended by Grace, as well as other West High robotics members.

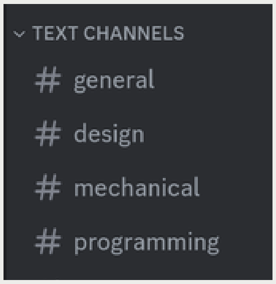
## Image Plastics

While exploring new robot materials we got in touch with Image Plastics, a company that specializes in thermoplastics. They graciously donated scrap polycarb to our team, and we got the opportunity to talk with Dan, who gave us useful insights into the uses of thermoplastics. Notably he gave us useful advice on how to bend polycarb and acrylic, noting the difference between bending towards and away from the heat source.

# ASSISTIVE OUTREACH

## Mission

Our team has steadily been growing a large knowledge and skill base, and with next year being the last year for 4 of our members, we wanted to place a specific emphasis on spreading our knowledge and helping other teams, especially in the Anchorage area. We felt that there was a lack of community and camaraderie among Southcentral teams, and have worked over the course of the season to change this by providing help and assistance to teams whenever possible.




## Anchorage Alliance

As part of our goal to create a stronger sense of community among Southcentral FTC teams, we founded the Anchorage Alliance Discord server. Inspired by FRC style open alliances, it has created a safe space where teams can interact, freely ask for advice, share their knowledge, or just hang out. It also drastically increased coordination across schools, especially regarding tournaments.

- **Members from 14 FTC teams**
- **All Anchorage teams**
- **12,000+ messages since kickoff**
- **74 members**

## Mentoring

As the most experienced team at West High, we know that it is important to provide advice and mentor the other teams in the club. This season, we mentored teams 16660 and 22323 in both hardware and software. Additionally, our lead programmer Manning is a well respected member of the Anchorage FTC community and has provided valuable advice to numerous teams before and during competitions, including but not limited to 12656, 4951, 16970, and 3825.

### 22323 Iron Nest

**Software:**

- **PID**
- **Teleop enhancement theory**
- **Debugging skills**

**Hardware:**

- **Intake Design**
- **Lift limit switch**
- **Problem identification, analysis, and solving**

### 16660 Technofeathers

**Software:**

- **PID**
- **Voltage Compensation**

**Hardware:**

- **Intake Design**
- **Decision making advice**
- **Hanging with slides**

## Electronic Discharge (ESD)

During League Meet 3, many teams struggled with ESD, a hard to prevent phenomenon that can cause unexpected disconnections. Following the competition we researched preventative measures, and came equipped to future competitions with dryer sheets and staticide spray that were available to other teams and event organizers to ensure a more enjoyable experience for all.

# STRATEGY/DESIGN PROCESS

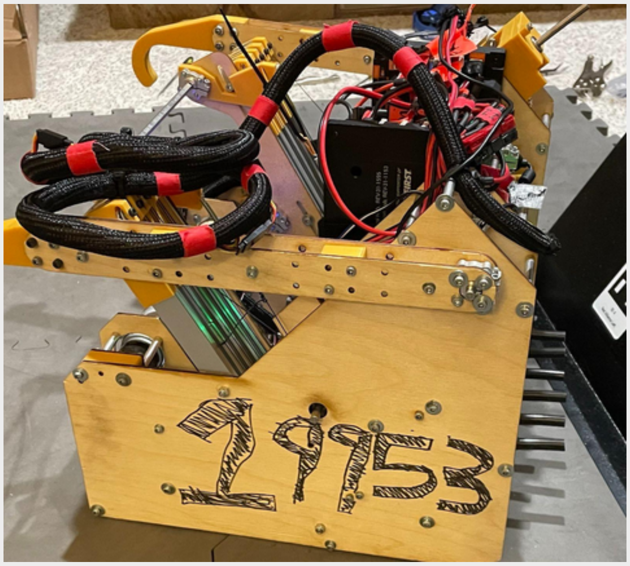
## Strategy

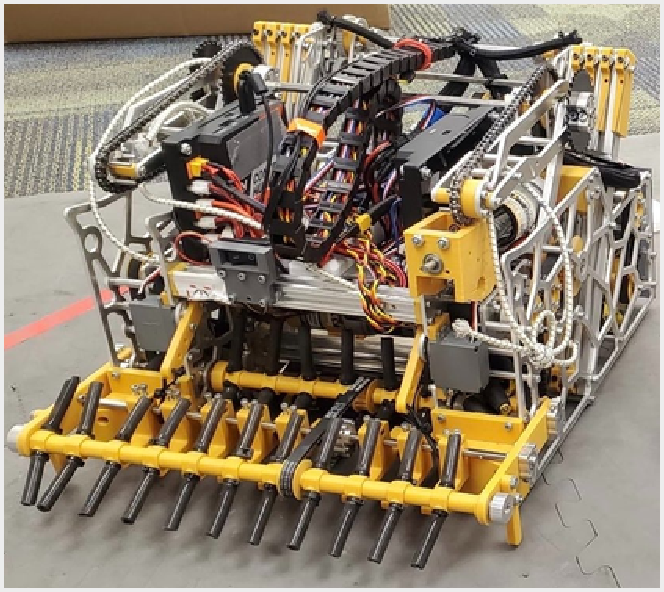
- Autonomous
  - Very important in qualification matches
  - Less important in elimination matches due to difficulty of coordination
  - Lots of cross field movement requires good localization
    - Odometry pods for small scale localization
    - April tags for relocalization and large scale
- Teleop
  - Fast cycle times to allow for line bonuses
  - Lining up rotationally and front/back cost the most amount of time when scoring
    - Rotational -> PID controller on the robots heading that allows the robot's heading to lock perpendicular to the backdrop
    - Front/Back -> 2 Infrared sensors provide distance from the backdrop, inverse kinematics correct for robot distance from backdrop (pg. 15)
  - Mosaics provide a lot of points
    - Independent release of each pixel
    - Precise placement
- Endgame
  - Consistent hang and drone are mandatory for competitive play

## Design Process

**Brainstorm** -> **Prototype** -> **CAD** -> **Assemble** -> **Integrate** -> **Test** -> **Reflect**

Each of our primary mechanisms (drivetrain, intake, outtake, hang) went through a round of initial brainstorming. The first ideas were tested, designed, and eventually assembled and integrated into a complete robot. We competed with this robot for the first 2 league meets, and after reflecting on our performance we realized that our design had fundamental flaws (pg. 9, 10, 11, 12) that would make it entirely noncompetitive at the state level. We began a complete redesign that involved replacing **every single part** and making **complete redesigns** of all our main mechanisms. After endless testing and iterating, including a weekend where we worked upwards of 120 hours in 4 days (The Great Rebuild!) this eventually developed into our current robot.



*Left: V1 pictured pre League Meets*

*Right: V2 pictured pre State*

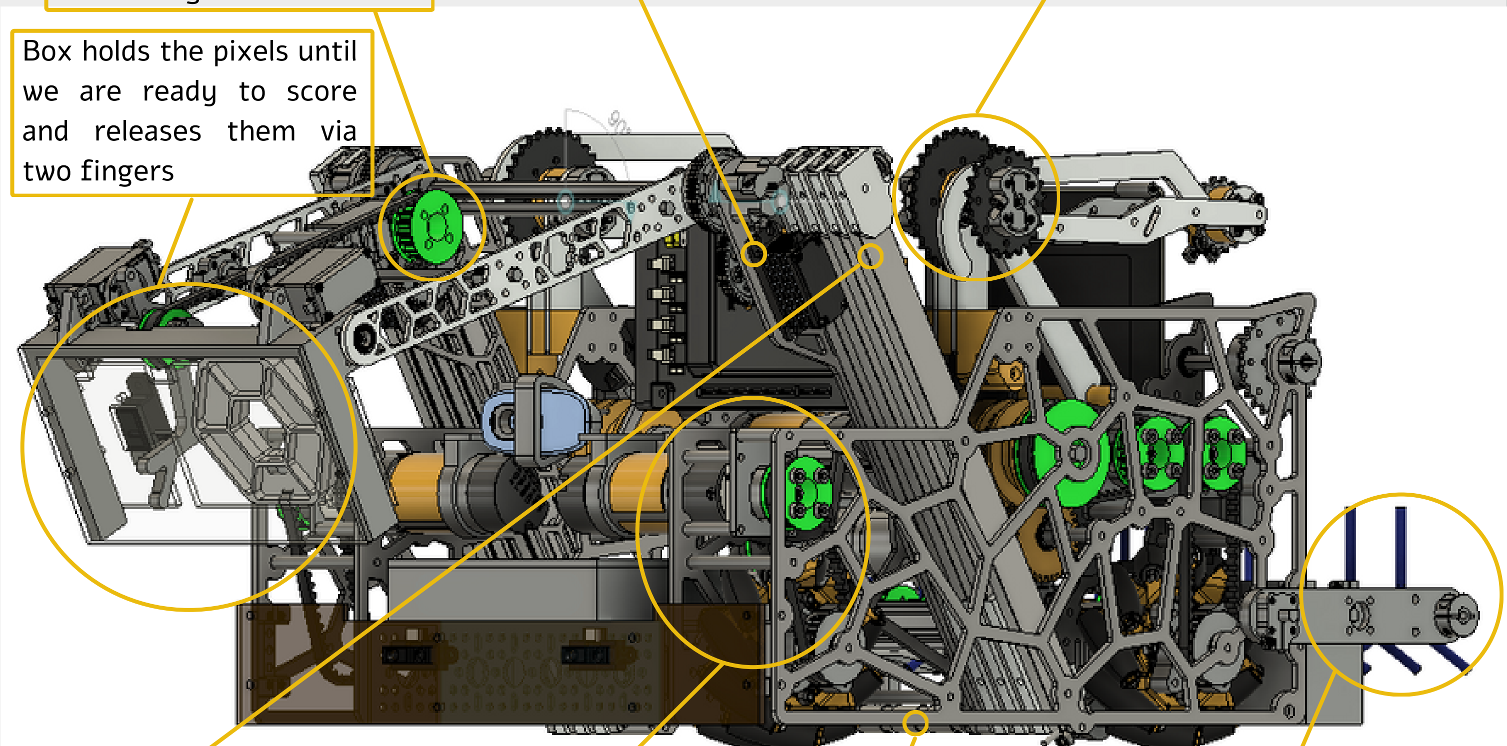
# Robot Overview

Servo controls the pitch of the box and matches it to the angle of the backdrop for scoring

Arm pivot servos powers the arm so we can score farther away from the back drop

Hook mounted to a ratio virtual 4 bar powered by a worm gear box to hang off of the truss in end game

Box holds the pixels until we are ready to score and releases them via two fingers



Linear slides allows us to score on the entire height of the backdrop

Drivetrain is powered using belts and pulleys

Counter roller spins upwards to lift pixels off the ground and into the box

Surgical tubing brushes start the pixel transfer process by sucking up the pixels. “Touch it own it” style intake

## Performance

### Scoring capabilities

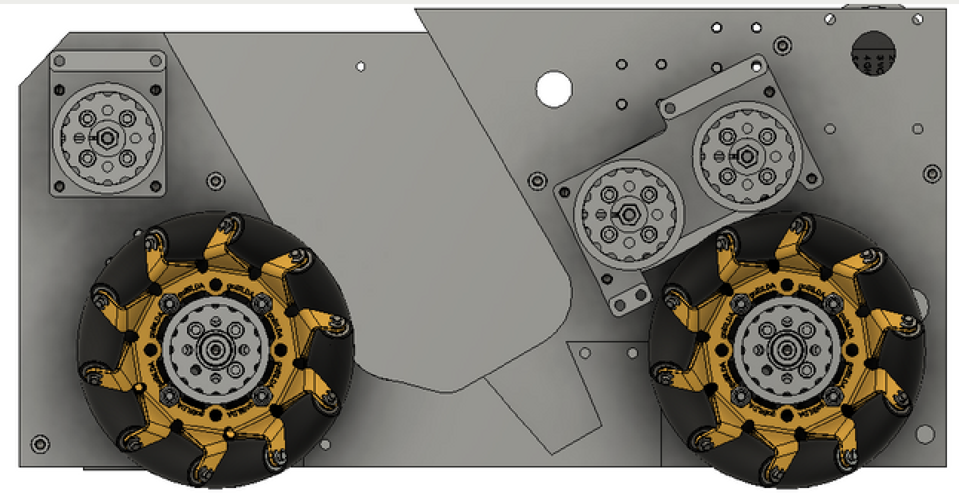
- Auto
  - 2+0 - Preloaded pixels w/ randomization bonus
  - 2+1 - Audience side, preloaded pixels + 1 stack pixel
  - 2+2 - Backdrop side, preloaded pixels + 2 stack pixels
- Teleop
  - Score 15 cycles in 2 minutes in practice, 10 with robot interference
  - 3+ mosaic(s) stacking up to the 2nd line
  - 132 points during practice teleop
- Endgame
  - 20 Point Hang
  - 30 Point Drone

### Statistics

- 70 Points scored per match on average
- 45 TBP1 which is a metric based on autonomous performance
- 23-7 win-loss ratio
- Part of 3 of the top 10 match scores in Alaska
- Average OPR (average points scored) across competitions
  - LM1 - 52.01
  - LM2 - 60.39
  - LM3 - 32.34 (1st comp with new robot)
  - League Tournament - 66.99
  - Open Qualifier - 70.14

# DRIVETRAIN

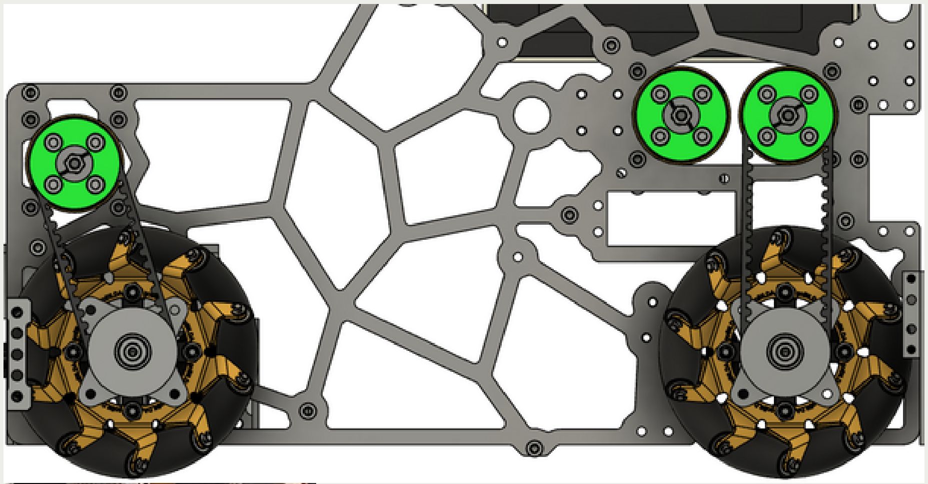
## Chain Drive



## Ver. 1

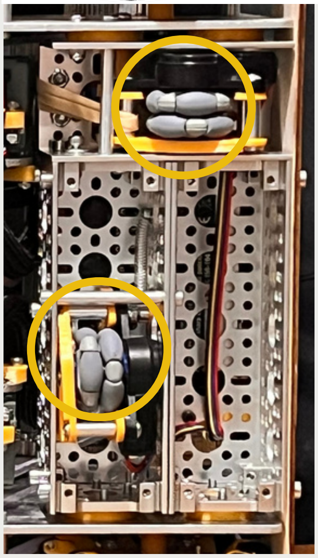
- First iteration of the drivetrain
- Chain transmission powered by 312 rpm motors
  - A **lot of slop** led to imprecise auto and teleop
- Mecanum wheels on dead axles
- Parallel plates made out of wood would **bend**
  - The bending caused distances to be **out of tolerance** creating large amounts of **friction**
- Short drive base
  - **Caused tipping issues**
- Cross field time: 6-7 secs

## Belt Drive



## Ver. 2

- Belt drive with 435 rpm motors
  - **Minimal to no slop** allow for more accurate auto and teleop
  - 435 rpm motors allow us to achieve a **higher top speed** than 312 rpm motors
    - The 435 rpm motors **pull a lot of power** when driving, causing other issues and inconsistencies
- Aluminum plates instead of wood
  - The stiffness of the aluminum keeps distances within tolerance and **reduces the friction** in the drivetrain
  - The extra weight of a heavier material combined with faster motors limits acceleration
  - -> Aluminum was pocketed in V2.5 which saved ~3.1 lbs, allowing for **faster accel** and **less current draw**
- Odometry Pods
- Longer wheelbase **prevents tipping**
- Cross field time: 3-4 Secs



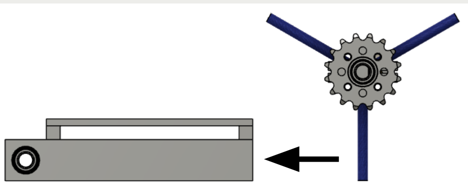
## Odometry Pods

- A mechanical solution to localization
- A pair of two unpowered wheels with Rev Through Bore Encoders
  - The dead wheels rotate as the robot moves around
  - The rotation of the wheels are kept track of by the Rev Encoders
  - Allows for extremely **accurate positioning** in auto

# INTAKE

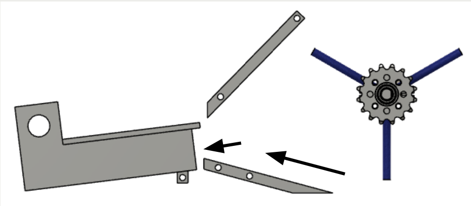
## Ver 1.

- First attempt at an active Intake
- Pneumatic tubing
- Ramp integrated into box
  - Pixels would slide out
- Roller far away from ramp
  - Large "**dead zone**" where pixels got stuck, not fully transfered, but out of reach of the roller
- Inconsistent and performed poorly when it worked
- ~3 second transfer



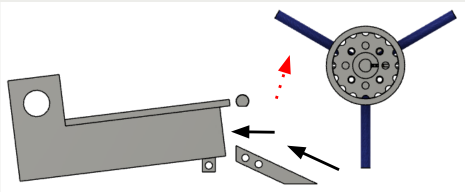
## Ver 2.

- Separated ramp from box
- Added floor and roof funnels to constrain the pixels movement
- Suffered from large "dead zone"
  - Transfer was inconsistent, but worked well when successful
- Pixels would get caught by the roller halfway into the box, and fling the box upwards
- **Ramp damaged the field tape**
- ~3 second transfer



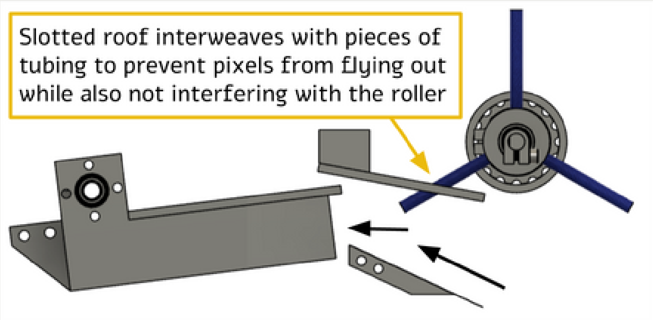
## Ver 3.

- Greatly reduced "**dead zone**" by moving roller closer to box
- Added fixed bar in front of box to prevent the roller from flipping it upwards
- Pixels that didn't transfer fast enough were spun backwards and **flung out** of the robot, resulting in a launch penalty
- Worked semi-reliably and performed well
- ~2 second transfer



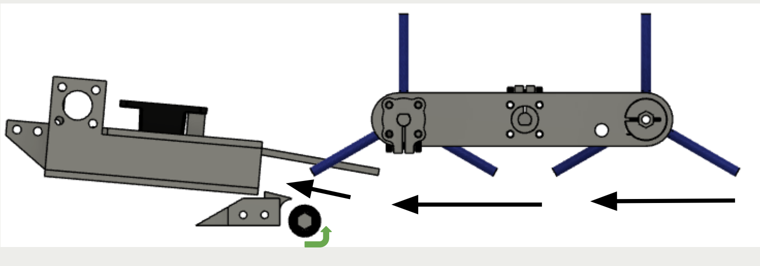
## LM1 & LM2

- V1-V3 were built on a test chassis designed for the sole purpose of testing the intake
- First intake installed on a real robot
- Switch from pneumatic tubing to **softer tubing** -> jammed less frequently
- Added **slotted roof** that went between the rollers to prevent pixels from flying upwards
- First design that fully constrained the path of the pixel -> more consistent transfers
- Pixels **did not auto sort** in the box, which caused jams when both pixels were not intaked simeultaneously
- ~2 second intake, 2 second transfer




## LM3 - State

- Replaced ramp with **counter roller**
  - More reliable and doesn't tear up the field
- **Wider box** allows for **better auto sorting** in box
- Added pivoting outer roller
  - Raised by flexible zip ties to prevent the servos from breaking on impacts
  - Allows for intaking off the stacks during auto
  - Much **wider** -> faster driving and cycling
- Added color sensors to automatically detect pixels
  - Faster transfer, fewer human inputs necessary
- ~0 second intake, ~ 1 second transfer



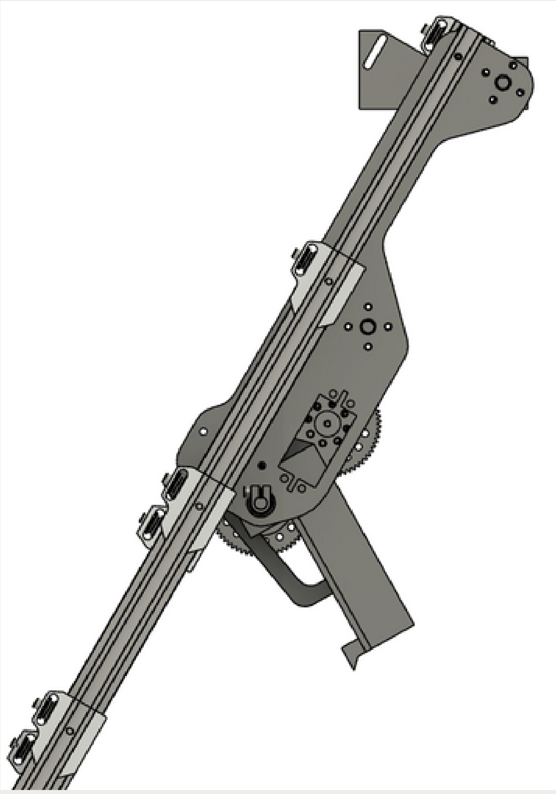
# OUTTAKE

## General Concept

- 60 degree angled slides
  - Angle matches that of the backdrop
  - Misumi drawer slides are very smooth and lightweight
    - Faster extension
  - Box to hold and deposit pixels

## V1

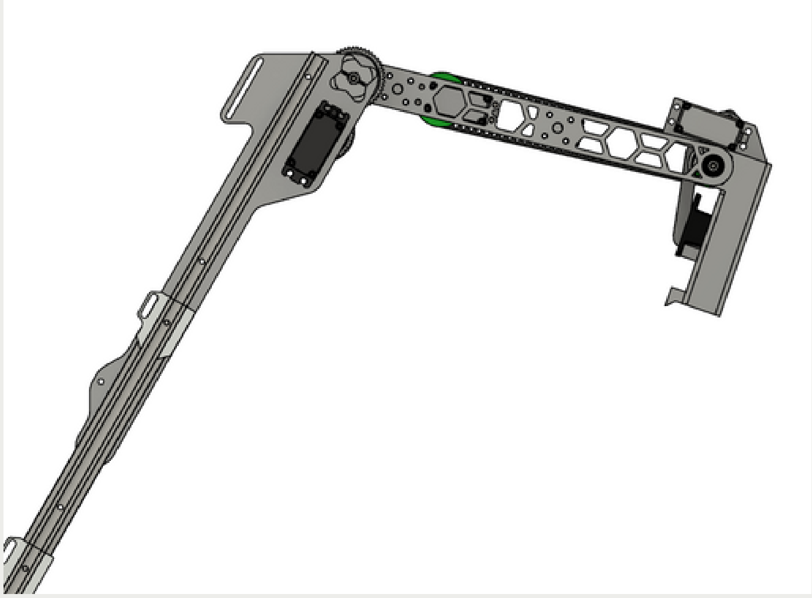
- Designed so the deposit spacing was perfect when the robot was pressed up against the backdrop
  - Robot would sometimes **knock pixels off** the backdrop
  - Robot **couldn't score** when pixels were on the ground in front of the backdrop
- Box was not angled flush against the backdrop, deposited at a 60 degree angle relative to the backdrop
  - **Less consistent deposits**



*V1 in CAD: Note the angle of the box in the deposit position, and the lack of horizontal extension in front of the slides*

## V2

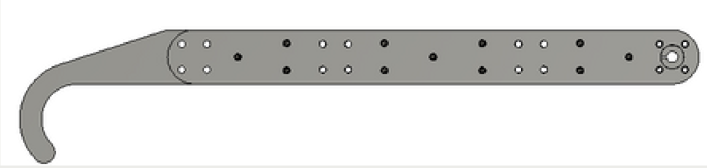
- 9" arm powered by 2x Axon Max+ Servos
  - Servos have analog output which allows for accurate positional control
  - Arm allows for horizontal extension (see pg. 15 for automation)
    - Can **extend over grounded pixels**
    - Can deposit without slamming robot into backdrop -> **lower chance of knocking pixels off**
  - Box is flush with backdrop when depositing
    - Much **more consistent deposits**
    - More **control** when making mosaics



*V2 in CAD: Note that the box is flush with the backdrop when depositing, as well as the large amount of horizontal extension provided by the arms. This solves many of the issues associated with V1*

# HANG

## V1

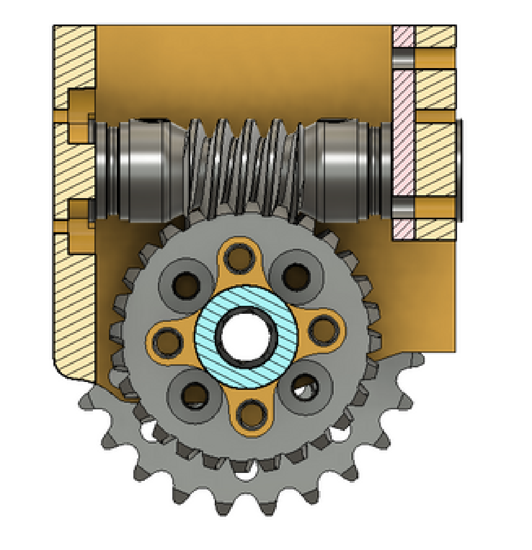


### Basic Idea

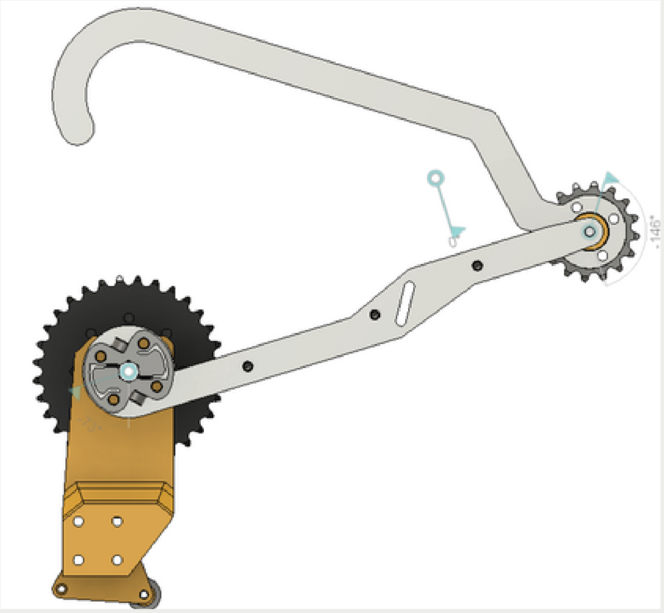
- Pair of hooks on both sides of robot
- Swung up and hooked onto truss to hang
- Powered by a worm gear drive

### Pros/Cons

- **Easy** to implement
- Made robot **wider**
  - **Harder to manuever**
  - Drive shaft twisted, causing the robot to hang unevenly



## V2



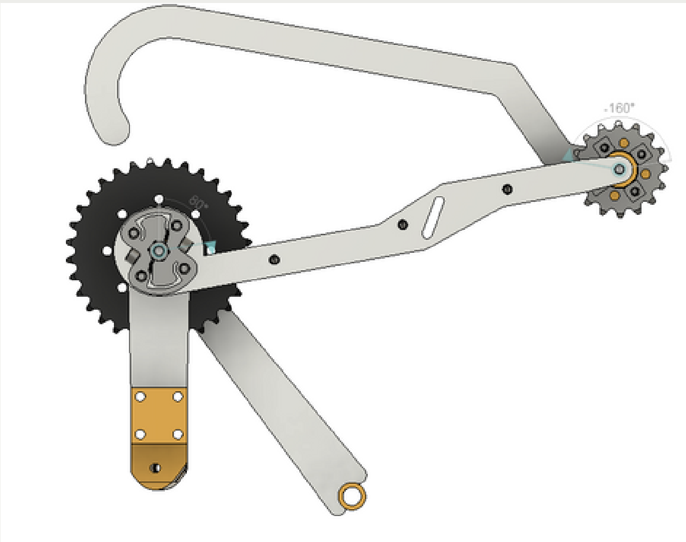
### Changes

- Virtual linkage system
- Main structure is **aluminum**
- Built in tensioner for the slides
- Switched from 6.35mm to 8mm shafts to decrease twisting

### Pros/Cons

- More compact -> **narrower robot**
- Not rigid
  - 3dp mount **could not handle high loads**
  - Mount would twist, causing chain center to center to shorten, **allowing the chain to skip**

## V2.5



### Changes

- All load bearing structures are **aluminum**
- Aluminum brace for **stability**
- Added counterspringing to reduce force on the motor

### Pros/Cons

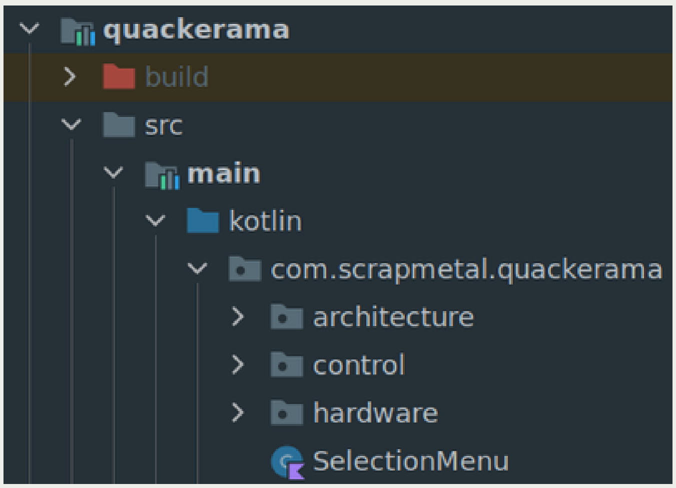
- Aluminum mounting bracket
  - **Not prone to breaking under high loads**
- Brace prevents mounting bracket from twisting which stops the chain from slipping

# SOFTWARE: GENERAL

## Languages

- **Kotlin, not Java**
  - All of our code is written in Kotlin
  - Much more expressive and less verbose than Java: halved lines of code in some areas
  - Experiment with new languages and more functional style of programming
- Custom Kotlin-based **Domain Specific Language** for easy path creation for auto

```
val parkPath = path { this: PathBuilder
    line { this: PathBuilder.LineBuilder
        label("backdrop to park")
        start(backdropPose.position)
        end(parkPose.position)
        constraints { this: PathBuilder.Li
            decelDist( d: 16.0)
            heading(toRadians(0.0))
        }
    }
}
```

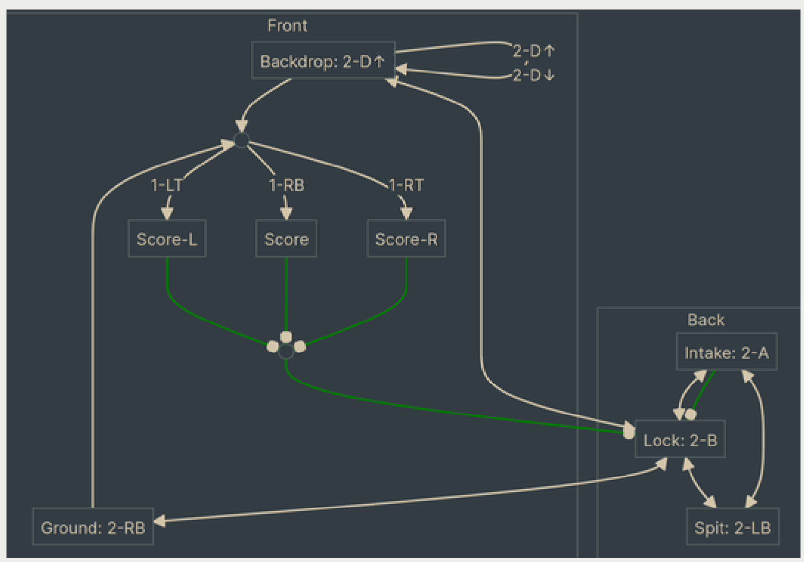


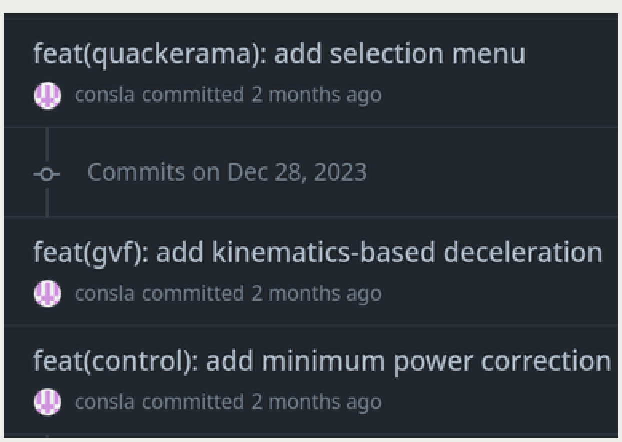

## Quackerama Library

- Developed a **custom utility library** called Quackerama (ducks <3) for easy reuse season after season, with complementary KDoc
  - Hardware device wrappers for motors, servos, etc.
    - Cache writes to speed looptimes, concise utility functions
  - PIDF controllers, asymmetric motion profiles, custom path following (pg. 15), etc.
  - And more!

## Finite State Machine

- Robot structured as a finite state machine to **guarantee robot behaviours**
  - Makes code cleaner and less likely to run into bugs
  - Drivers only trigger state transitions instead of manual control
  - Safeties to prevent triggering of potentially dangerous state transitions (e.g. clipping pixels post-scoring)



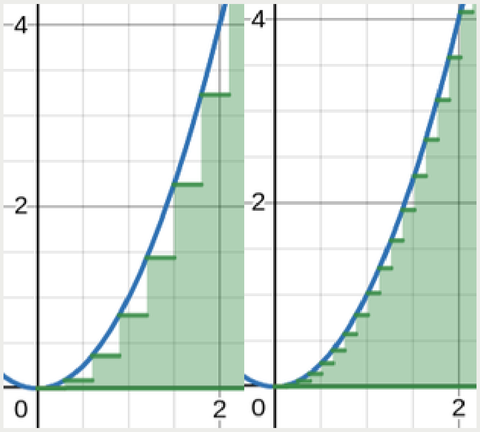

## Git + GitHub

- Use Version Control Systems to maintain our code
  - Follow the **industry standard** of Git Conventional Commits
- All code is **publicly available** on our GitHub repo for others to study and learn from under the BSD 3-Clause Clear License

# SOFTWARE: CONTROLS

## Loop Frequency

- High loop frequencies needed for high performance
  - Better PID control, more accurate odometry localization, etc.
- Solution: cut out expensive and redundant hardware calls which bottleneck performance
  - Average loop frequencies **up over 700%** from **30 hz** -> **250 hz**
    - Lift PID -> can be tuned far more aggressively without oscillations
    - Odometry -> more accurate



*The effect of smaller timesteps on odometry accuracy (Riemann sum)*

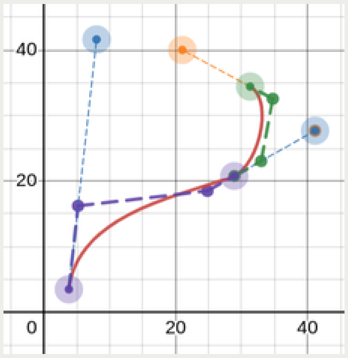
## Motion Profiles

*X-axis: time*
*Red: position*
*Blue: velocity*
*Green: acceleration*

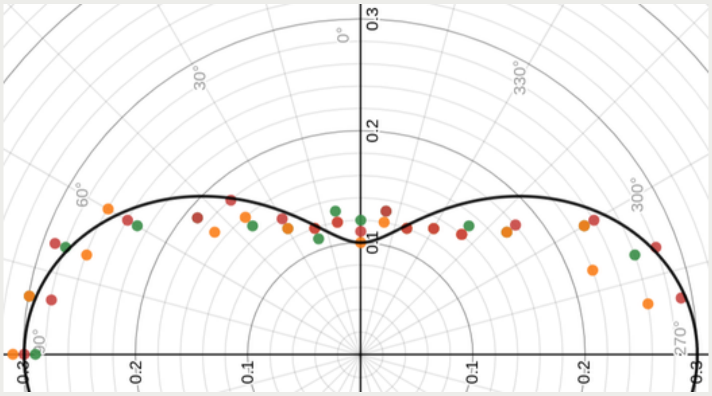
- Quick outtake arm had **large oscillations** at the end of movements
  - Outtake box got **caught on robot internals** due to overshooting the target position
- Solution: use asymmetrical trapezoidal motion profiles
- Move to desired position with continuous velocity and slower deceleration
  - Outtake arm comes to a stop with **no oscillations**

## Modeling

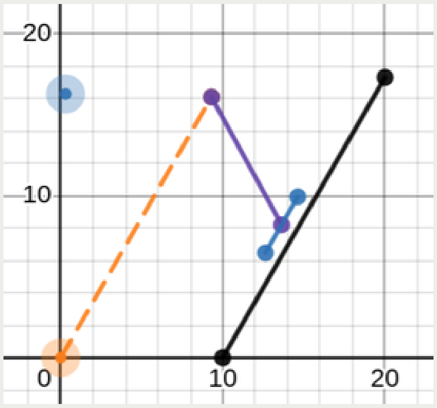
- **Paradigm shift** from last season: use **real life measured performance** instead of theoretical mathematical models, and **simulate algorithms** before attempting on bot, using programs like Desmos
- Measurements
  - Find minimum power to move drivetrain in each direction to avoid steady state error: **improved autonomous precision** by 200%
  - Regression between distance sensor's analog voltage and actual distance to improve accuracy
- Test algorithms
  - Cubic Hermite splines for custom pathing
  - Inverse kinematics for outtake (pg. 15)



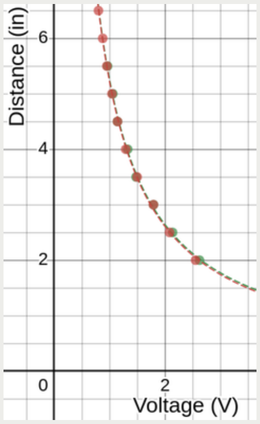
*Testing cubic Hermite splines with polynomial coefficients for our custom pathing*



*Minimum power to move drivetrain as polar graph in 10 degree increments*



*Robot outtake and backdrop simulation to test inverse kinematics algorithms*

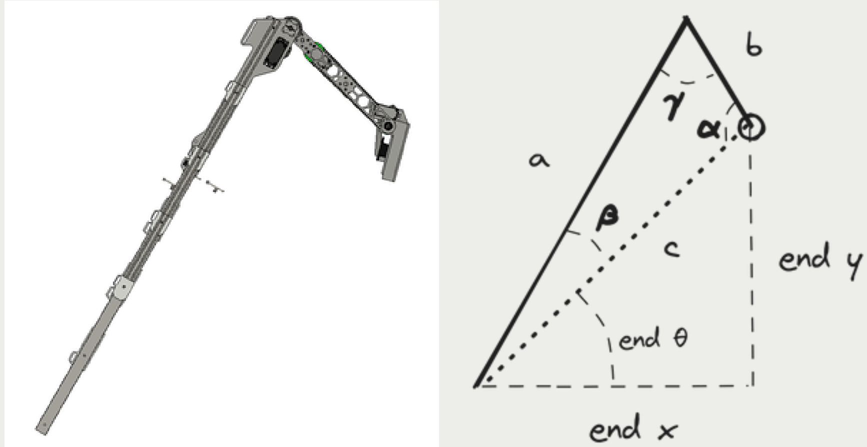



*Per-sensor regression between voltage and distance*

# SOFTWARE: CONTROLS

## Inverse Kinematics

- #1 Killer of cycle times: needing to spend precious seconds aligning
- Scoring sequence is almost completely automated
- Outtake has 2 degrees of freedom: tilted slide extension + arm pivot
  - Allows for **independent horizontal extension** while maintaining the same vertical height using math: automatically correct for varying distances from backdrop
  - Additional 6 inches of redundancy in both autonomous and teleop and reduces need for time-consuming forward/back alignment



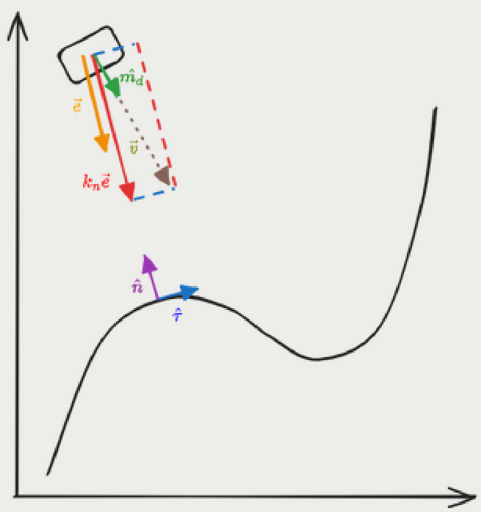

*Our outtake subsystem and corresponding mathematical model*

$$\gamma = \arcsin\left(\frac{c\sin(\beta)}{b}\right) \qquad a = c\cos(\beta) \pm \sqrt{b^2 - \sin(\beta)^2 c^2}$$

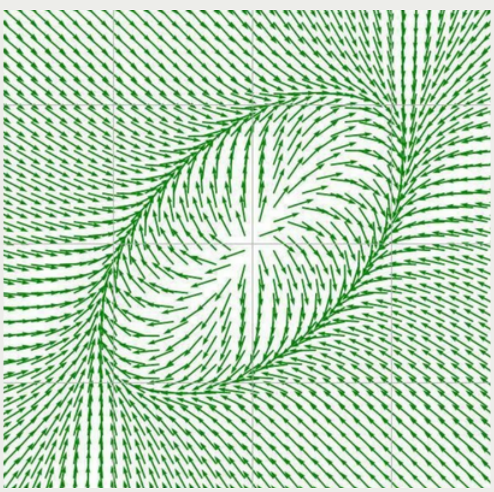
*The equations we derived from scratch to find the required arm angle and lift extension respectively*

## Guiding Vector Fields

- **Custom path following** instead of pre-built libraries like Roadrunner
  - Attempt to create something more performant
  - Better control, flexibility, and tuned for our purposes
  - Learning experience!
- Uses a relatively recent algorithm called a guiding vector field (GVF) that combines vectors to converge onto a specified path
  - Cubic Hermite splines for paths (pg. 14)
  - Common algorithm in autonomous fixed-wing aircraft
- Developed mid-season from October to December
- Wrote a 15 pg research and documentation paper on our findings for others to study
- Used for all of our current autos
- Integrated into our Quackerama library (pg. 13)



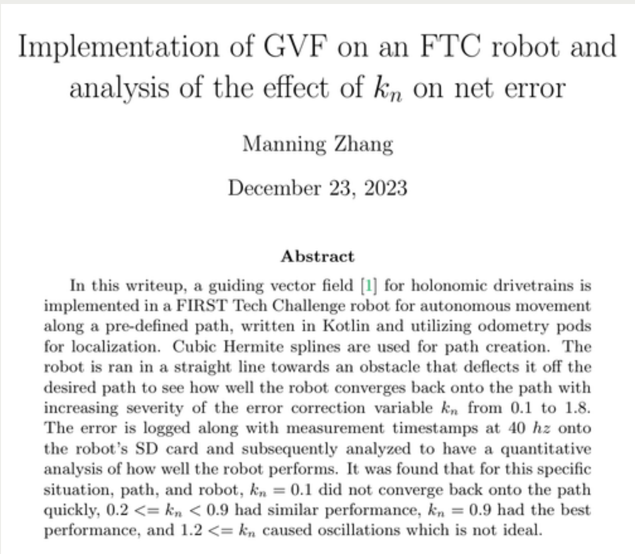

$$\vec{v}(x,y) = \hat{\tau}(x,y) + k_n\vec{e}(x,y)$$



*Up and left: a graphical depiction of how a GVF works along with the principal equation*

*Left: an example of a GVF for an ellipse. Following the arrows from any point will converge to the ellipse*

*Right: cover page for the resulting research paper*



Implementation of GVF on an FTC robot and analysis of the effect of $k_n$ on net error

Manning Zhang

December 23, 2023

**Abstract**

In this writeup, a guiding vector field [1] for holonomic drivetrains is implemented in a FIRST Tech Challenge robot for autonomous movement along a pre-defined path, written in Kotlin and utilizing odometry pods for localization. Cubic Hermite splines are used for path creation. The robot is ran in a straight line towards an obstacle that deflects it off the desired path to see how well the robot converges back onto the path with increasing severity of the error correction variable $k_n$ from 0.1 to 1.8. The error is logged along with measurement timestamps at 40 $hz$ onto the robot's SD card and subsequently analyzed to have a quantitative analysis of how well the robot performs. It was found that for this specific situation, path, and robot, $k_n = 0.1$ did not converge back onto the path quickly, $0.2 <= k_n < 0.9$ had similar performance, $k_n = 0.9$ had the best performance, and $1.2 <= k_n$ caused oscillations which is not ideal.