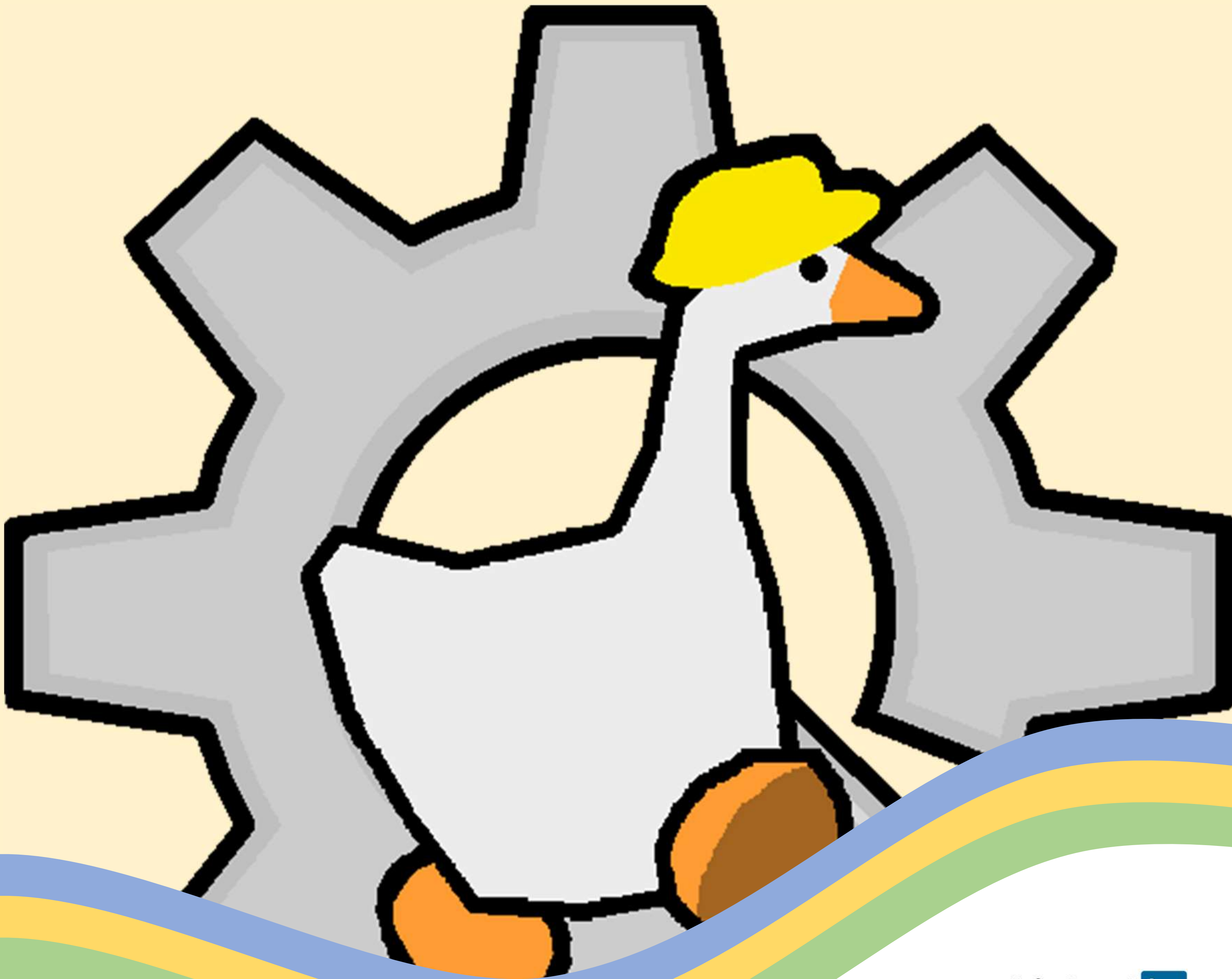
FTC QUACKOLOGY 19508



FIRST

CENTERSTAGE

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USEL
US ENGINEERING LEAGUE
YOUTH ROBOTICS COMPETITIONS

MOTOROLA SOLUTIONS FOUNDATION

AT&T

MEET OUR TEAM

(Left to right) Back: Vick Ye, Ian Wang, Yutian Wang, Andrew Sun, Mark Tang, Eddy Wang, Alec Zhong. Front: Andy Ye, Lucas Chen, Kenny Huang, Grace Zhang.
Shot in front of our facility (US Engineering League (USEL)).

Team Roles

Captains: Andrew, Ian

Hardware: Andy, Alec, Kenny, Ian

Software: Vick, Eddy, Ian, Lucas

CAD: Andrew, Ian, Mark, Grace, Alec

Outreach: Andrew, Yutian, Ian, Grace

Team Info

Team 19508 Quackology was founded in 2021 during the FTC Freight Frenzy season. Our home facility is at the USEL center, which we share with our sibling team 11392 Defenestration.

Mission

Our goal is to facilitate a learning environment for members to pursue hardware, software, and business-related components of robotics, as well as to spread the good word of FIRST programs through community events and forge connections in our local municipalities.

TEAM PLAN

Recruitment & Sustainability

We recruit new members from doing **outreach events** in the community, such as the summer camps we host. Our plan for rookie members involves giving them as much **hands-on experience** as possible during the off-season.

Financing

- Support **local** organizations through sponsorship deals
- Email for external sponsorship opportunities
- Use **community connections** for sponsoring

Goals

Community
- ❑ Reach 5,000 people
- ❑ 500 hours of community outreach
- ❑ Attend 5 events

Team
- ❑ Recruit 2 people
- ❑ Reach world competition
- ❑ Organize team structure

Robot
- ❑ Implement Roadrunner, April Tag, Sensor Filtering
- ❑ Develop team strategy

Year in Review

We were able to **reach** all our goals (except reaching world competition) so far. We **exceeded our community goals** and recruited **twice as many new members** and were able to implement the desired concepts onto our new robot design.

MOTIVATING THE COMMUNITY

We made 9,000+ impacts through outreach events like workshops, camps, and social media.

π Day: Meadow Glens Elementary

We held a station where we showed our robot to the elementary school students and described FIRST programs. Additionally, we talked to Congressman **Bill Foster**. 200+ participants

Block Party: Arabian Avenue, Naperville

We showcased our robot and **filmed a news segment** about FIRST for **NCTV17**. We also met the mayor of Naperville, **Scott Wehrli**, and city councilman **Paul Leong**. 100+ visitors.

Summer Camp: USEL Center, Naperville

We hosted a camp for middle-schoolers. We taught robot fundamentals, designed a mock-competition, and spread information about FIRST. We recruited **2 new members** through our camp.

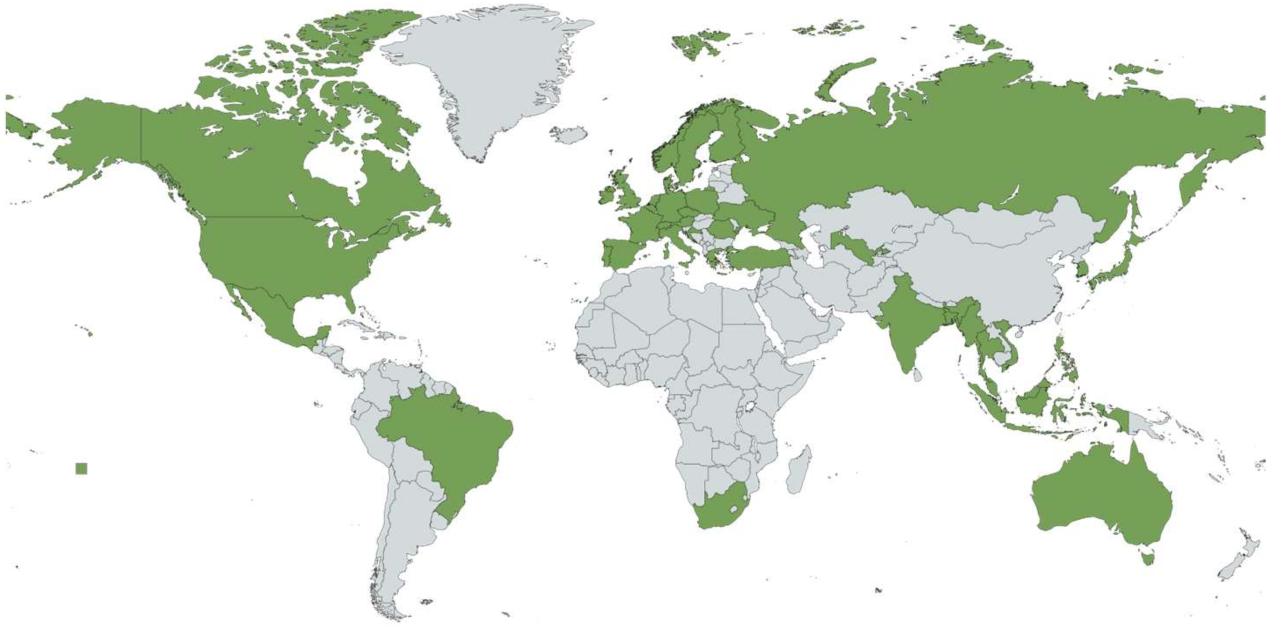
Robot Workshop: USEL Center, Naperville

We hosted a free workshop for community members, particularly younger students, to come explore robotics and learn about software, hardware, as well as the FIRST robotics programs. (15+ students)

Sumobot Competitions: Naperville

We helped USEL administer Sumobot competitions by mentoring participants on robot construction and refereeing the matches. In total, we were able to reach over 500+ students and parents.

Social Media



The 40 countries in green represent where our videos have been viewed.

7,495 views on YouTube.

41 hours of watch time.

14+ teams assisted online*.

The Comments Section

@user-nr8pb1rz7
Nice! Sending love from team 19477 bit by bit!

@mohamedabdahamed7099
Thank you very much @ftcquackology

@JoshuaThe-xp2jb
I love this!

@hemavundela1188
Great job you legitimately one of the best frc teams

***Assisting** a team is defined as providing communication helping with FIRST program specific issues or providing funding/supplies. We have assisted teams through Discord forums and YouTube comments, as well as providing supplies for 21350 Team Rocket.

FORGING CONNECTIONS

We converged with city officials and career professionals on topics involving education and FIRST.

Mentors & Coaches

Jian Sun (Engineering, Panduit)

Coach Sun provided his mechanical expertise to guide our hardware design with stringing the pulley design. He has also helped organize team events and mentor rookies.

Fred Xu (Project Management, Abbot)

Coach Fred has assisted the team with lessons on data collection and analysis to foster discussions of game strategy and development.

Bing Zhong (Sr. Design Eng.)

Coach Bing used his career experience to mentor the CAD team in their productions. He gave us tips on how to design our drone launcher.

State Officials

Scott Wehrli (Mayor of Naperville)

Mr. Wehrli was at the Block Party and was a part of our discussion with Mr. Leong on STEM education and its future with robotics.

Paul Leong (Naperville City Council)

We met former 203 School Board member and current city councilman Paul Leong at the Block Party, where he taught about applications of robotics education.

Bill Foster (Representative, IL 11th Dist.)

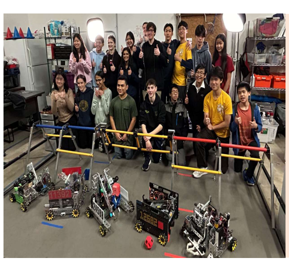
Mr. Foster is the only PhD physicist in Congress. We had 2 meetings with Mr. Foster, where we showcased our design and learned from his career at Fermilab.

Local Robotics

FIRST ILLINOIS ROBOTICS

FIRST Tech Challenge Illinois

We reached out to FTC Illinois, and they supported us by providing us with minibots to utilize for more interactive demonstrations in our workshops and our summer camp.



Regional FIRST Tech Challenge Teams

We **hosted 2 scrimmages**, partnering with **7 total teams:** 11392 Defenestration, 21350 Team Rocket, 24588 WEGO Rookie Cookies, 12682 The Golden Ratio, 18149 Cybernetic Squirrels, and 19652 7ech!neers. At our scrimmages, we collaborated on game strategy and shared robot designs to learn from each other.

CONTROLLING AUTO

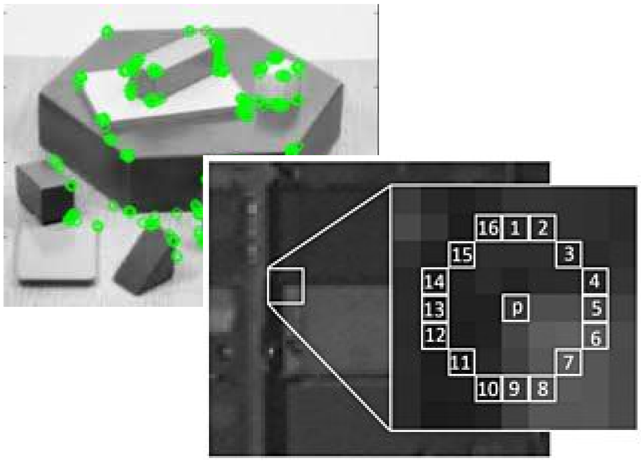
We implemented and integrated new systems into our autonomous to provide efficient movement.

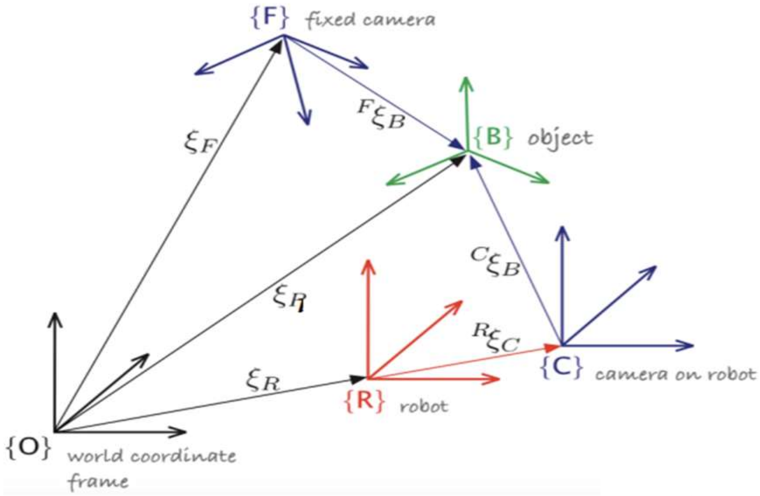
ORB Detection

Oriented FAST and Rotated BRIEF

FAST: Corner detection algorithm
- Analyzing intensity differences in randomized circle

BRIEF: Descriptor for feature point
- Convert keypoint to binary vector, reduce noise with Gaussian blurring





AprilTag

Relative positioning with tags

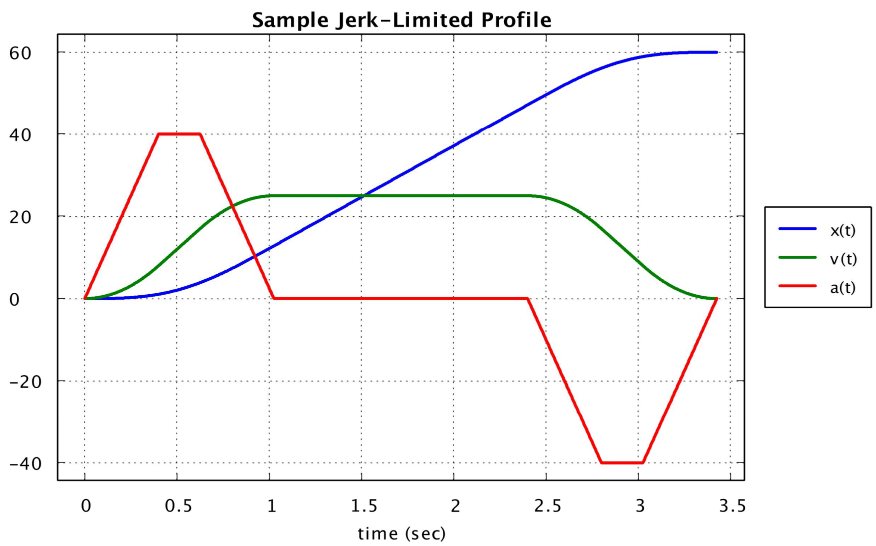
- Utilized the Lie group SE(3) to represent transformations
- Transformed relative position to global position

Roadrunner

Pathmaking with odometry

Our robot uses 3 odometry wheels for maximum accuracy.

GENERAL ACTIONS
- **Feedforward loops** estimate power needed to reach a location.
- **Feedback loops** correct errors.
- **Mecanum kinematics** manipulate mecanum wheels.
- **Splines** facilitate continuous movement.



Example of basic motion-planning, v0 being actual

Sensors Fused:

- IMU (Inertial Measurement Unit)
- Odometry Wheels
- Camera

PID Control

Proportional, Integral, Derivative

We used PID to accurately control our lift movement.

- **Proportional** depends on error: its influence decreases with error.
- **Integral** accounts for accumulation of errors over time to eliminate steady-state error.
- **Derivative** considers error's rate of change with respect to time to anticipate future errors and slow down.

$$P = K_p \cdot e(t)$$

K is gain $\quad e(t)$ is error at time t

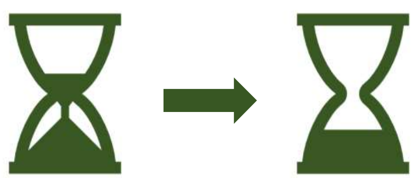
$$I = K_i \cdot \int e(t)\, dt$$

K is gain $\quad \int e(t)\, dt$ is integral of error over time

$$D = K_d \cdot \frac{de(t)}{dt}$$

K is gain $\quad \frac{de(t)}{dt}$ is derivative of error with respect to time

Default **With FL**



60 Seconds → 15 Seconds = **75%** Increased productivity

FTC FastLoad

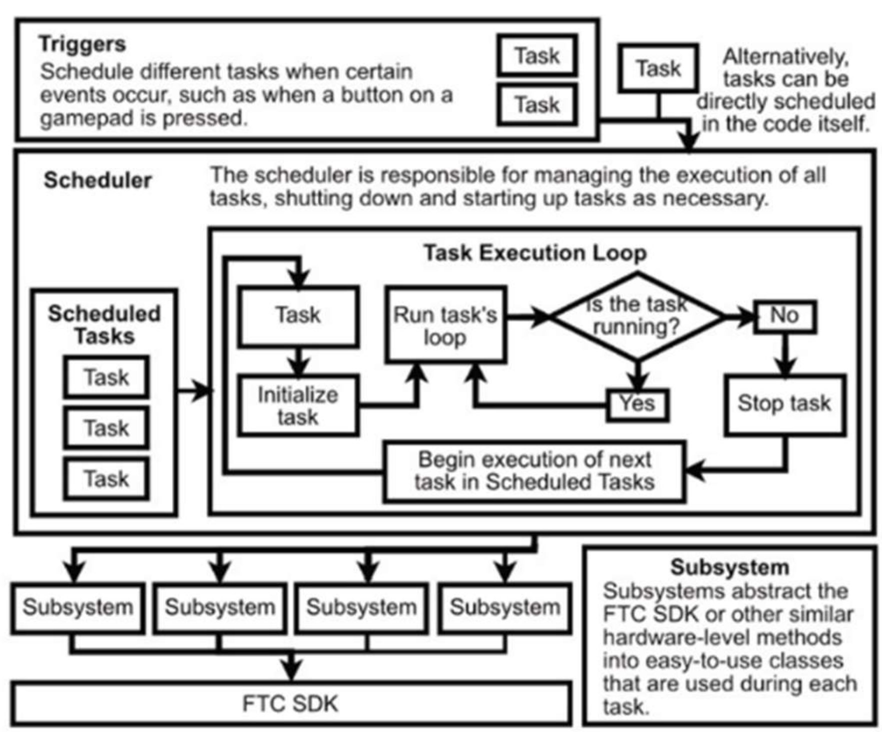
Improving Loading Efficiency

Uses a **Gradle Plugin** to build the fast load bundle, and a **library** to reload the bundle without restarting the app. By loading new code faster, we can be **over 75% more productive.**

Sequoia

Finite State Machine/Task Scheduler

- Splits robot into **subsystems**, defines **state** and **actions** into **Tasks**
- Tasks can be run **conditionally, parallel, in sequence,** and in **races**
- Without Sequoia, pulley and claw tasks cannot run simultaneously



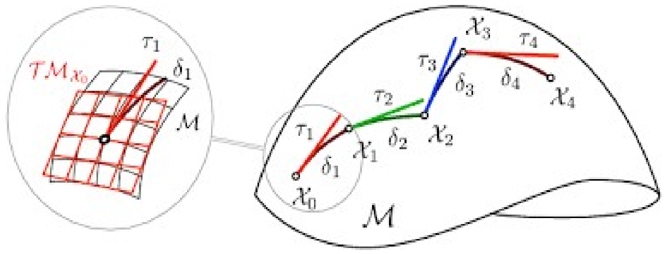
THINKING BEYOND

In order to refine our software, we integrated advanced mathematical and scientific concepts.

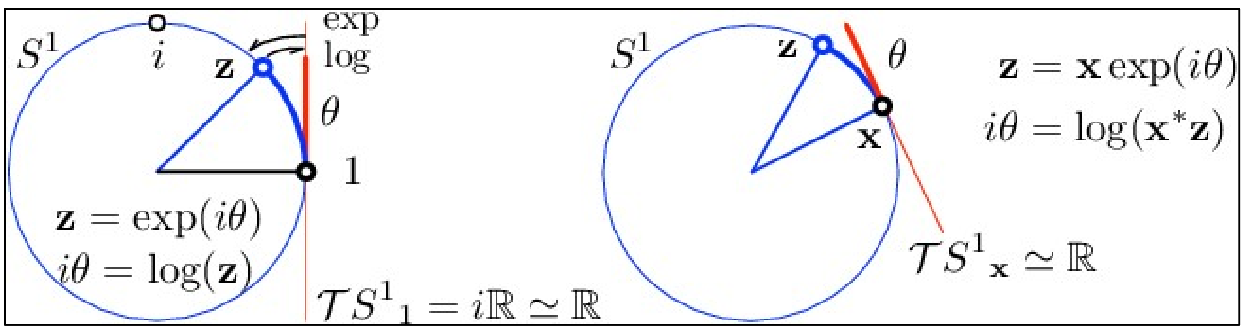
Lie Theory

Relating linear space to nonlinear

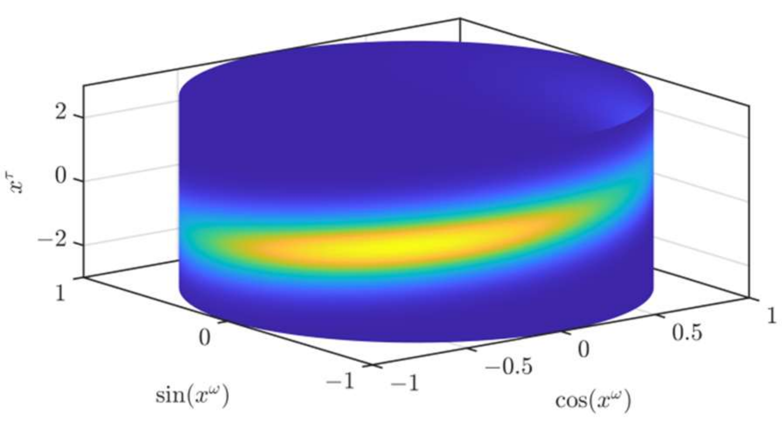
- Respects symmetries of the topology of the space
- Encapsulates differential motion in manifold space
- Utilized SO(2), SO(3), SE(2), SE(3) groups
- We use it to represent pose and motion of the robot



3D manifold is mapped onto linear plane.



Lie theory maps nonlinear manifold space onto linear vector space.



Representation of x and heading elements of SE(2)'s state space.*

SE(2) State Space

The SE(2) Lie group represents **transformations in 2D space** (ex: rotations and translations).

Each point in this space represents a possible pose. The probability density is represented by color (yellow represents more likely).

*Pfaff, F., Li, K., & Hanebeck, U. D. (2021). The State Space Subdivision Filter for Estimation on SE(2). Sensors (Basel, Switzerland), 21(18), 6314. https://doi.org/10.3390/s21186314

Bayesian Filtering

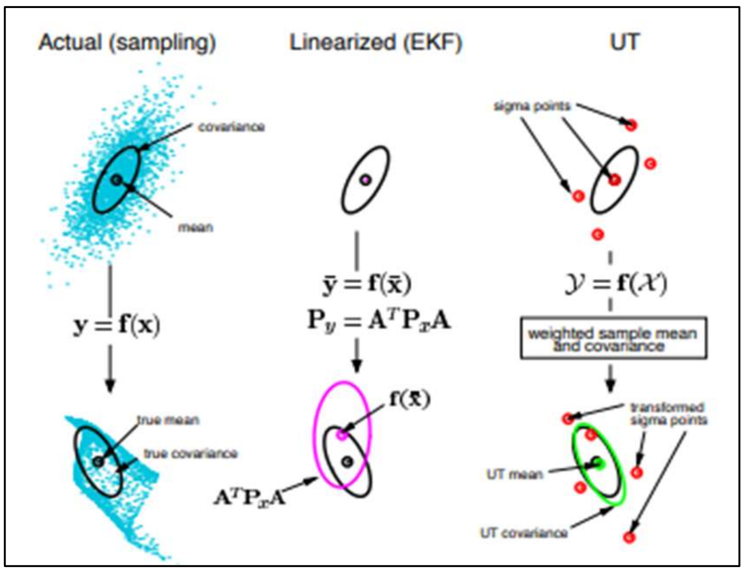
Prior and posterior robot pose estimation

Kalman Filter	UKF	EKF	UKFM	IEKF	S3F (SE2)	Particle Filter
•Linear •Unimodal •Deterministic •Static accuracy	•Non-linear •Unimodal •Deterministic •Static accuracy •Tuning parameters •Sampling	•Non-linear Unimodal •Deterministic •Static Accuracy	•Non-linear •Unimodal •Deterministic •Static accuracy •Act on Manifolds •Tuning parameters •Sampling	•Non-linear Unimodal •Deterministic •Static Accuracy •Act on Manifolds	•Non-linear Unimodal •Deterministic •Improvable Accuracy •Act on Manifolds •Sampling	•Non-linear Multimodal •Randomness •Improvable Accuracy •Act on Manifolds •Sampling

Systems are listed in order of least accurate to most accurate (least time complexity to most time complexity).

Accuracy

Time Complexity



UKF vs EKF vs UKFM vs IEKF

UKF, EKF: Nonlinear variation of Kalman filter – same performance.
UKF, UKFM: Approximates the gaussian by linearizing the gaussian of a sample propagated through nonlinear function.
EKF, IEKF: Approximates nonlinear propagation function by linearizing as a Jacobian.
UKFM, IEKF: Act on Lie groups, respects symmetries of state space topology.

Square Root UKF

$$\Omega_{t+1} = \sum (x_i - \bar{x})(x_i - \bar{x})^T$$

$$\begin{bmatrix}\sqrt{A}\\ \sqrt{B}\end{bmatrix} = QR \qquad \sqrt{A+B} = R$$

$$[\sqrt{A}\sqrt{B}]\begin{bmatrix}\sqrt{A}\\ \sqrt{B}\end{bmatrix} = A+B$$

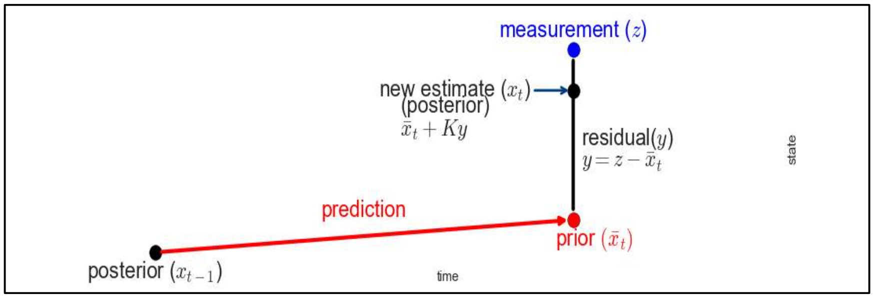
$$= R^T Q^T QR$$

$$= R^T R$$

UKF relies on deterministic sampling: state x, covariance $\boldsymbol{\Omega}$.
Sample $x_i = x + R_i$ where subscript i represents the column and $R * R^T = \boldsymbol{\Omega}$.
R is calculated through the Cholesky Decomposition which is susceptible to **numeric instability** (e.g. rounding).
By propagating the square root of the covariance and calculating it directly from the sample, we can avoid the Cholesky Decomposition, providing greater numeric stability.

UKF vs UKFM

Unscented Kalman Filter vs Unscented Kalman Filter on Manifolds

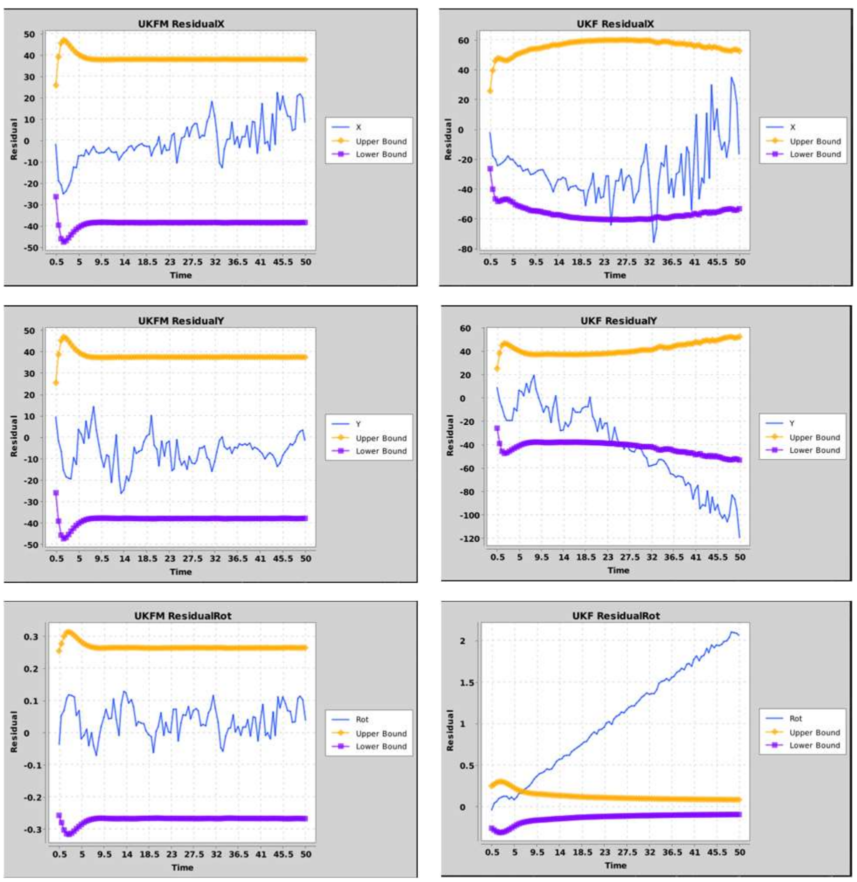


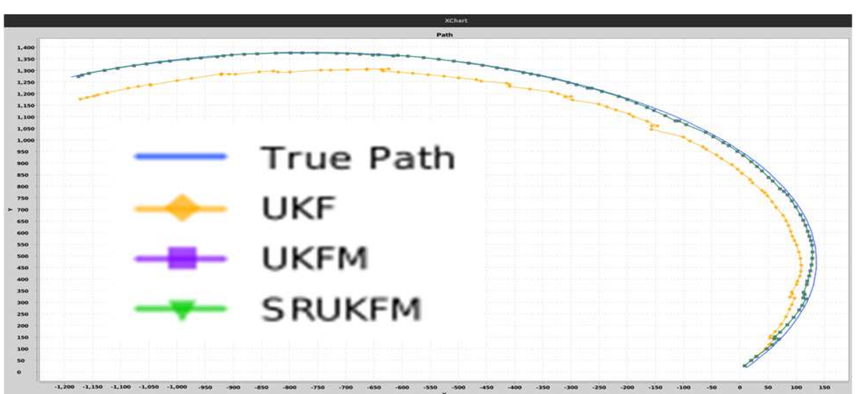
Kalman filters approximate the true mean by comparing the prior and measurement based off of reliability.

Ultimately, we had to choose between **UKF** and **UKFM** for our filter, based on accuracy and time complexities.

- **UKF** did not respect topology of rotations; captured error incorrectly

UKFM **UKF**





UKFM:
- Stable
- Errors are well-accounted for by standard error estimation

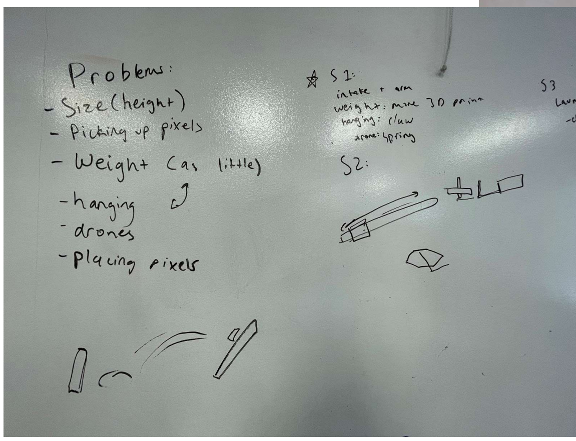
UKM:
- Unstable
- Diverging from true path
- Errors are not accounted for by the standard error estimation

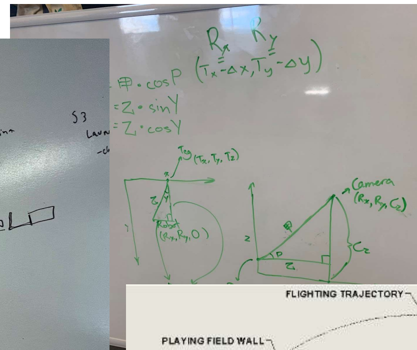
Due to the benefits of **UKFM**, we chose this variation over the standard **UKF**.

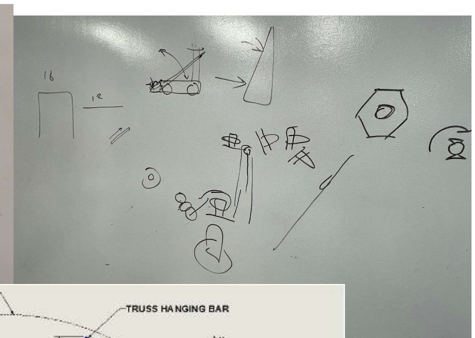
INNOVATING THE FUTURE

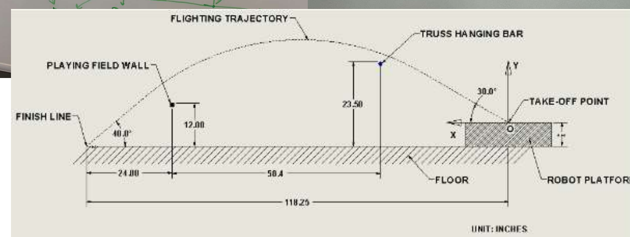
We underwent many iterations to improve our claw, pulley, drone launcher, and other designs.

BRAINSTORMING

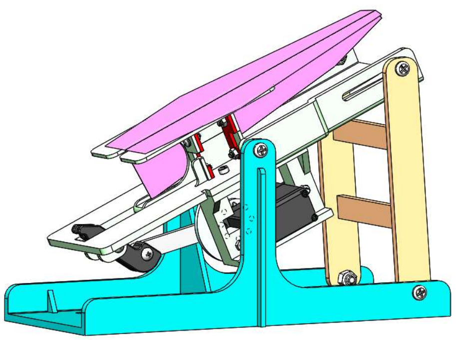


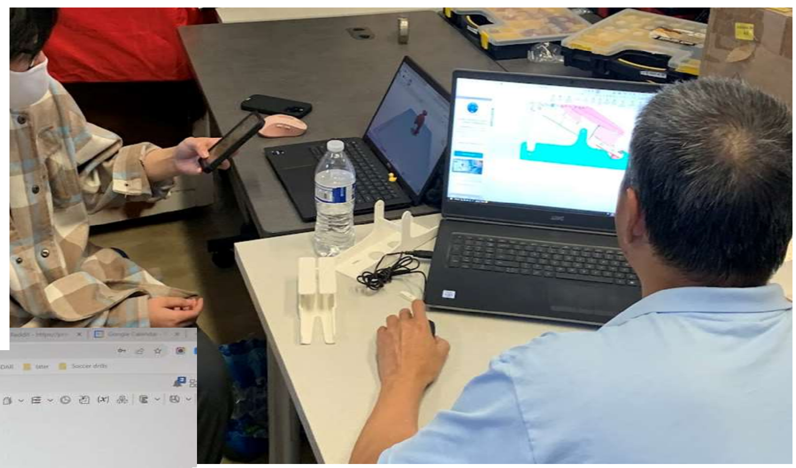


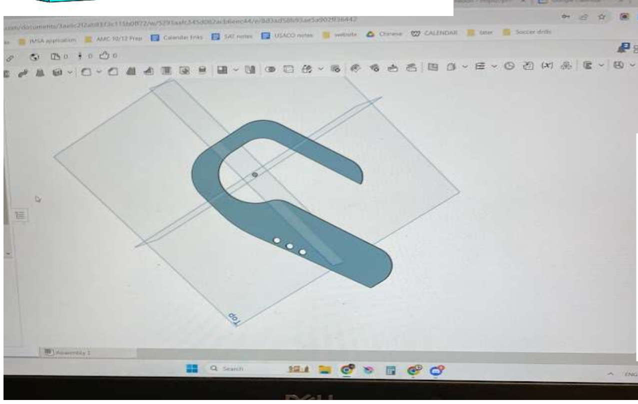




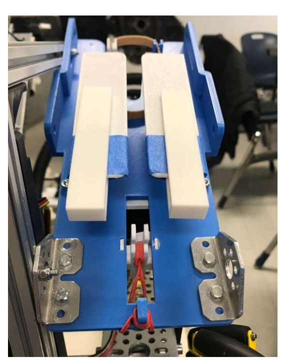
PROTOTYPING & DESIGNING







TESTING & BUILDING



ITERATIONS

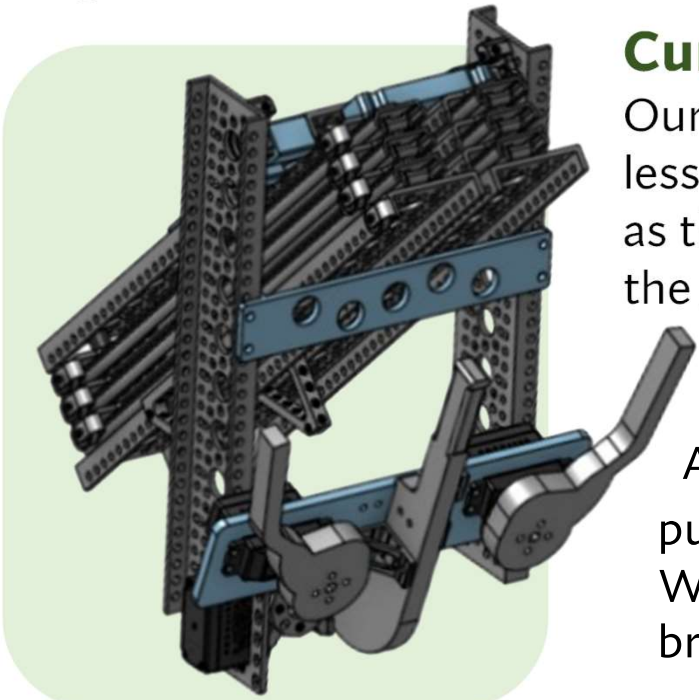
Pulley Evolution

Iteration One

Our first design used just one string, causing it to be unbalanced. Adding to the instability, there was just one set of pulley slides to hold it in place.

Iteration Two

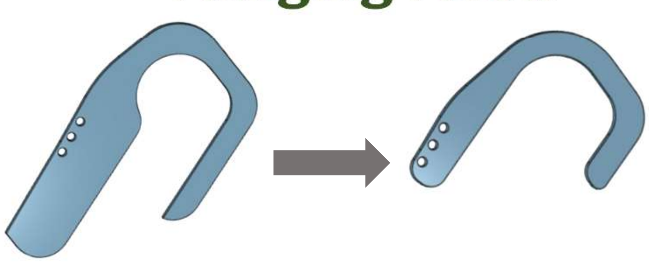
Keeping the single-pulley design, we added an antiparallel tension string to balance the force distribution and allow hanging.



Current Iteration

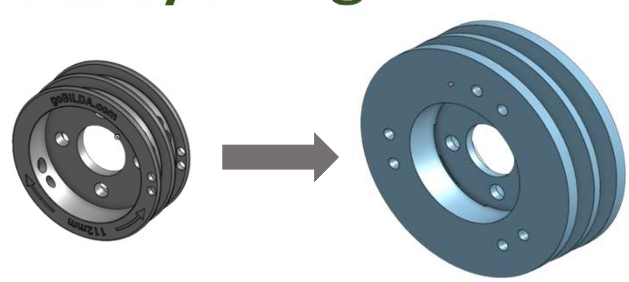
Our unstable lift system made us less consistent in picking up pixels, as the claw wouldn't align well to the ground. Therefore, we added a second pulley system, mounted to the chassis And connected to the first pulley, to stabilize the build. We also designed custom brackets for more stability.

Hanging Hook



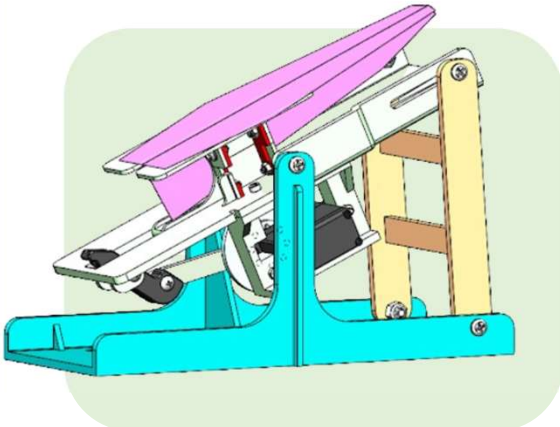
Original hook failed to hang & large size interfered with pulley string.

Pulley String Wheel



Original was too small; string would slip out. We made a custom wheel with larger rims.

Drone Launcher

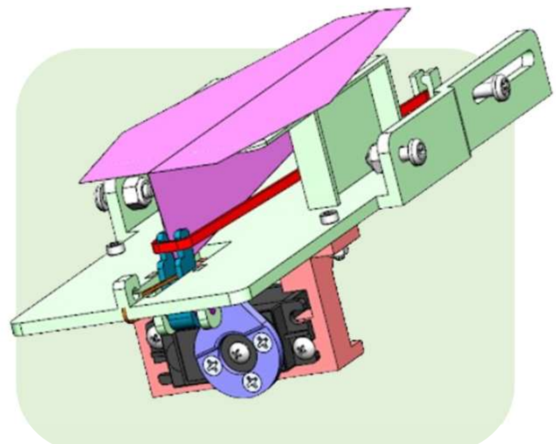


Iteration One

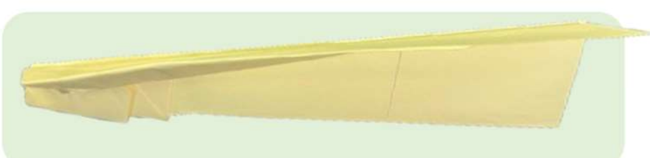
The first design had a large base. The trigger was mounted parallel to the drone, so the release was weak and unreliable.

Iteration Two

We mounted the launcher without a base to save space. Additionally, the servo was placed perpendicularly to the trigger for a more reliable launch.



Drone Evolution



Iteration One

The tail of this design separated too easily.

Iteration Two

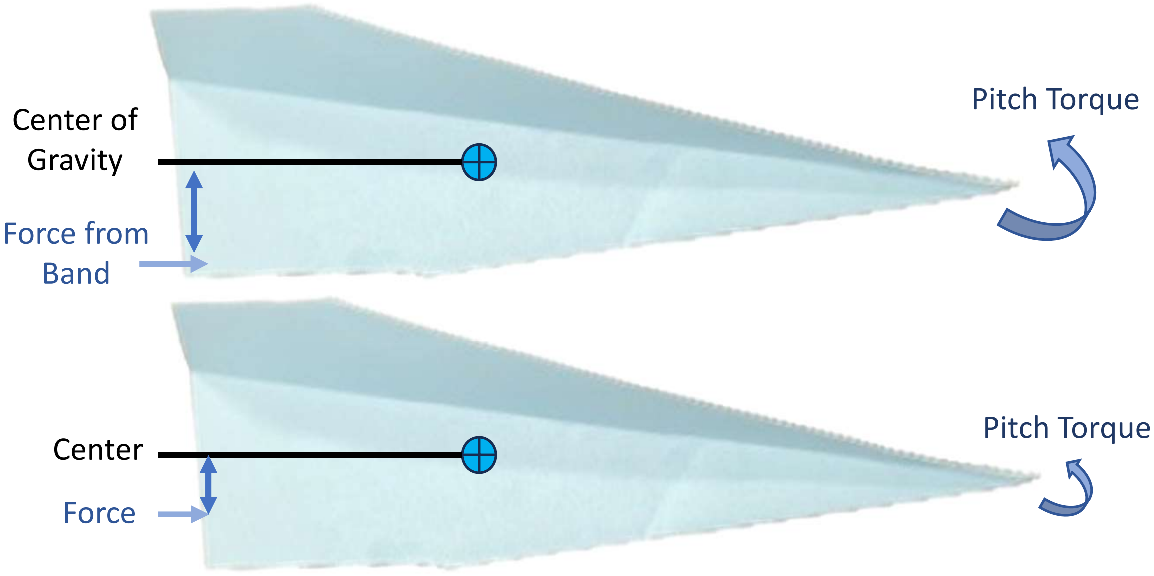
Added tabs to keep tail end together, but plane was too heavy.

Iteration Three

New delta design. Tail was too large to fit new launchpad.

Iteration Four

Simpler design. The tail is folded for more accuracy and reliability.

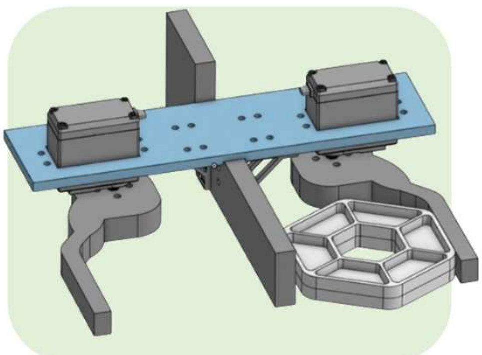


Modifying Pitch

Using physics, we adjusted the pitch of the drone by lengthening the trigger, so the force of the band aligns to the center of gravity.

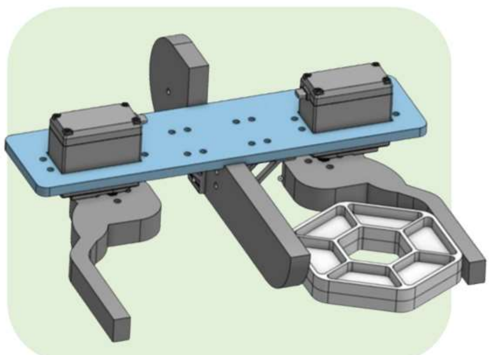
Double-Claw Evolution

Iteration One



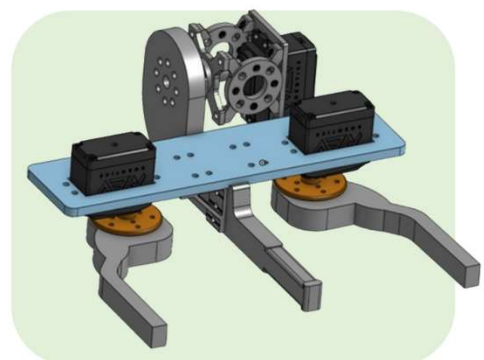
Unstable claw connection and drags on the ground.

Iteration Two



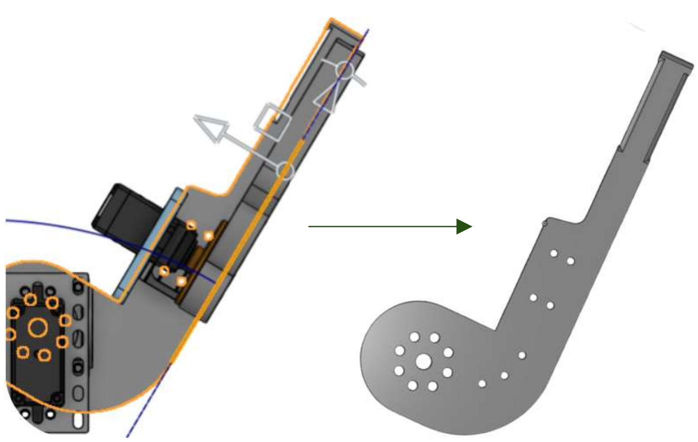
Smoother claw and more range of motion.

Iteration Three



Added servo box for stability. Redesigned the middle prong.

Current Iteration



- Servo box for maximum range of motion and stability
- Middle prong has ridges to apply rubber texture
- Sleek shape allows us to edit pixel placement on backboards for mosaics

DESIGNING WITH CAD

We used Onshape to design custom and efficient parts to bolster our robot.

❶ Drone Launcher

Our drone launcher uses a rubber-band and servo powered trigger to launch custom drone designs.

❷ Double Pulley

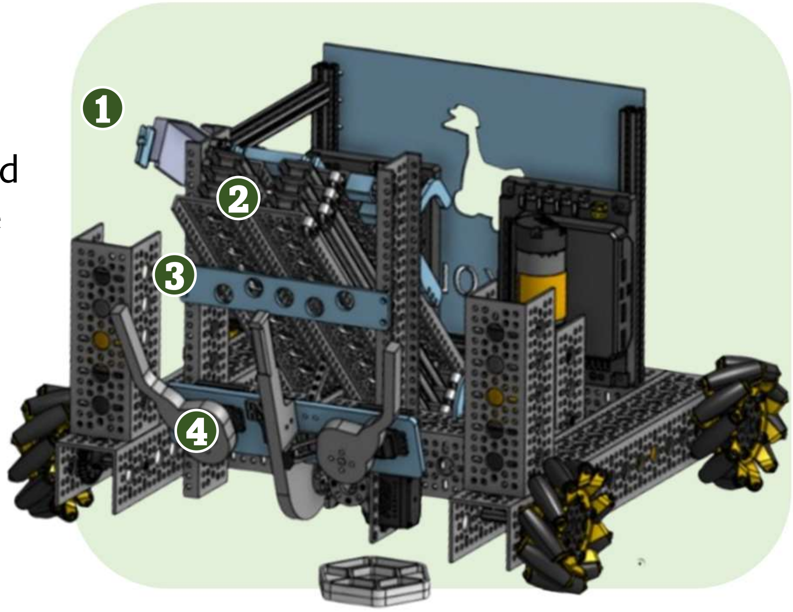
The double pulley has two strings running antiparallel to provide stability. It also uses hooks on the back to hang.

❸ Custom Brackets

We have 3 custom brackets to further stabilize the pulley.

❹ Claw

The trident design allows the intaking of two pixels at once. We used a servo box to eliminate side-to-side movement. Additionally, the servo's range allows a larger intake size to guarantee picking up pixels.



Other features:

Camera: Our robot features a Logitech C920 webcam, which provides a wide detection frame in auto. We 3D-printed a custom wedge to stabilize the camera angle.
Backplate: Polycarbon plate protects our hubs and looks stylish.
Odometry: Odometry wheels are spring-loaded for maximum accuracy.
Drivetrain: We use mecanum wheels.
Motors: Our motors are mounted to provide as much space as possible (some are vertical, and all are within the chassis).
Clearance: Our robot is designed to be low enough to pass through the truss gate.

Holes on Purpose

The holes in our design not only provide extra screw-fastening locations but actually provide more strength to the claw. Outside-facing edges are printed extra-thick, so holes act like pillars to strengthen the overall claw.