14943 Weber RamBots: Engineering Portfolio

Team Introduction

Hello! We are the Weber RamBots, FTC Team 14943 from The Weber School in Sandy Springs, Georgia. As a diverse group of students in grades 9-12, our team is focused on advocating for STEM education and creating a community that fosters the confidence to explore! Our responsibility as engineers and teammates lies in using our resources to extend STEM to those around us while discovering a passion for engineering, design, and innovation. This year, our team has set out to learn how to (1) use advanced manufacturing techniques, (2) acquire corporate sponsorships from local companies, (3) use advanced sensor fusion and mathematical analysis techniques, (4) improve team sustainability through extensive training programs, and (5) extend STEM education opportunities to surrounding communities.

Approach to Engineering & Design

Our team follows the engineering and design process when creating mechanical and software components of our robot; this process ensures that every member's voice is heard as many solutions to a design problem are considered before deciding to spend time and money on fabricating a final mechanism. Our process involves brainstorming, CAD, and empirical testing of prototypes.

Manufacturing Philosophy

As a high school, we are privileged to have access to a wide array of tooling and mentors with experience in manufacturing and custom design. Many mechanical parts of our robot are created from detailed Computer-Aided Design (CAD) iterations that team members develop throughout the season. After finalizing a solution in CAD, we often use laser-cutters and 3D printers to fabricate custom solutions to design challenges throughout the FTC season -- as we use different tools, we consider how to utilize our machinery in a safe and effective manner. Our team is also happy to provide manufacturing services to other FTC teams looking to delve into the world of custom-designed robots -- no matter how small the part, we're happy to show other teams the ropes and introduce a world of new possibilities.

Community Outreach Summary

Approach to Outreach

As a robotics team and, more specifically, a FIRST team, we believe it is within our responsibilities to carry out community outreach projects in order to best exemplify the idea of gracious professionalism and serve as a pillar of STEM in our community. We have taken on many community outreach projects in order to further our reach and the impact of STEM education in our community. We decided to create and work on outreach projects which can reach as many people as possible and which can bring STEM and STEM education to areas in which we noticed such programs did not exist beforehand.

The Epstein School STEM Coalition	People Reached: 230

*IMAGE TAKEN PRE COVID-19

Project Description The Epstein School is a Jewish day school in the city of Sandy Springs. Many students on 14943 came from The Epstein School where they attended elementary and middle school. The Epstein School and The Weber School are closely related, as both are Jewish community day schools in Atlanta. Our outreach at Epstein has consisted of The Weber RamBots starting an after-school robotics program at Epstein for students in grades 5-8 to participate in. Students from the Weber RamBots have met with Epstein School administrators and students to gauge interest in robotics programs and develop a curriculum to teach interested students about mechanical engineering, software development, teamwork, and different STEM fields. Members from 14943 serve as mentors to Epstein School students, providing design feedback, programming assistance, and teaching students how to use tools like CAD and project management applications. Before the COVID-19 pandemic, team members went in-person to Epstein every other week to work with students, answer any questions the students had, and provide design and programming suggestions. Since the pandemic, team members have switched to meeting online with students over Zoom to provide similar assistance, feedback, and fun. The Weber RamBots board worked closely with teachers to create a cost-effective program that fit within Epstein's budget -- the main vehicle for education are LEGO Mindstorm kits that are programmable and customizable for each student team!

Design Review With FTC 18304, FTC 17456

People Reached: 25

Project Description Throughout the three years that the Weber RamBots team has existed, we have been fortunate to cultivate long-lasting relationships with different FTC teams and community members. This season, design, CAD, and hardware team members offered to provide design reviews to rookie teams looking for feedback on how to accomplish game-specific tasks and optimize their designs. Team members first met with Stephen and Egan from FTC team 18304 Ultraviolet to discuss their 6-wheel and 8-wheel drives. Design and CAD members explained the advantages and disadvantages of non-holonomic drive systems as well as how to properly design around using a timing belt power transmission for the drivetrain. Later, design and CAD subteam members met with Atman and Ayyan from second-year FTC team 17456 Atlantis to discuss the physics of projectile motion and designing reliable, robust shooters for this year's game; much of the design review focused on how to create a shooter that gives rings enough spin and speed such that they can reach the high and mid goals while shooting legally from the launch line, and we also discussed some physics principles that Atlantis team members later incorporated into their shooter design!

FIRST Community Resources

People Reached: 100

Project Description During the summer and during the beginning of the ULTIMATE GOAL season, sub-team members from the CAD and hardware subteams as well as programming subteam students created two comprehensive community resources to assist teams who wish to learn more about custom manufacturing and motion profiles for controlling robotic mechanisms. The programming team's documentation explains the math that lays under the idea of a motion profile and how such ideas from industrial robotics can be applied to FTC robotics, notably in the fields of odometry and drivetrain localization. Programming team members released the documentation online on various FTC forums including Reddit and Discord where one hundred+ FTC teams now have access to starter code and mathematical explanations behind motion profiling. The design and CAD team worked with 10219 alumni to present a slideshow and Q&A on custom manufacturing and custom design at the ULTIMATE GOAL Georgia kickoff meeting to an audience of 50+ attendees. The presentation focused on CNC machinery and the design process.

Manufacturing With FTC 14470	People Reached: 20

Project Description One of the central goals of our team and school's fabrication facility is to extend our resources to other teams and individuals in the surrounding community who wish to experiment with, learn about, and use manufacturing technologies. In the early and middle of the ULTIMATE GOAL season, the Weber RamBots invited FTC team 14470 into the Weber School manufacturing facility to learn about laser-cutting and to laser-cut a few different versions of their drivetrain plates and mounting mechanisms for robot subsystems out of 5mm Plywood. Team members explained what laser cutters can be used for--including 2D cutting and light 3D engraving--as well as how to properly and safely operate a Trotec Speedy 400 class 3 laser!

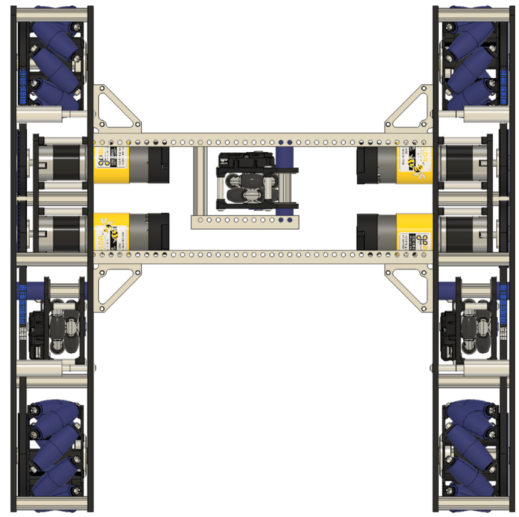
Engineering Community Connections	People Reached: 15+

Project Description To show our members what STEM fields and STEM professionals are like in the real world, we love to have industry connections and connections to our surrounding engineering communities. This year, we contacted Weber alumni who attended Georgia Tech and Virginia Tech and majored in Computer Science and Mechanical Engineering to tell us about their experiences as STEM professionals. One student who attended Georgia Tech, Justin Cobb, told our team about his different internships and work experiences working at robotics companies like KUKA, as well as his experience in state of the art robotics at Georgia Tech. Another student who attended Virginia Tech, Ross Williams, told students about his experience competing on a collegiate robotics team. Ross competes on Virginia Tech's robotics team which participates in the RoboMasters international robotics competition hosted in Shenzhen, China each year. Students then explained our FIRST and FTC programs to Ross and Justin, showed them our robot, and listened to the very helpful and kind feedback they both gave regarding our mechanical and software systems on the robot.

We have also contacted and spoke with professors at Technion University located in Haifa, Israel. Technion is one of the leading engineering institutions in the world, and we were very lucky to speak to Professor Moshe Shoham. Professor Shoham started MAZOR, a robotics company, out of Technion's business incubator in 2001. Professor Shoham explained how MAZOR was able to create novel robotic architectures to complete some of the most accurate robotic surgeries in the world. Recently, MAZOR was sold for 1.6 billion dollars to a medical technology company. We were also able to show Professor Shoham our robot and ask for his advice, and he was very impressed at the level of complexity of the robot and at the dedication of our members (we were very flattered!). Professor Shoham reminded students to stay organized, stay driven, and to follow our passions as STEM advocates.

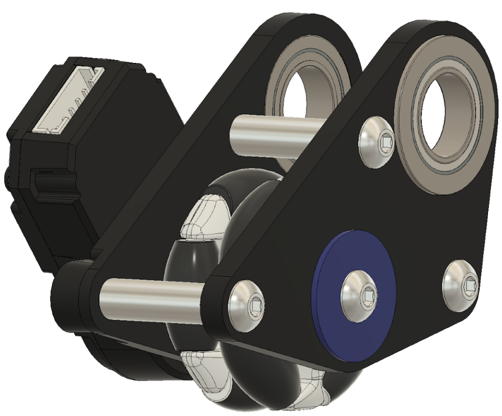
Mechanical Engineering Summary[1]

Drivetrain	Version 1.0



1.0 Subsystem Description Every game in FTC history has required the use of a drive base. For this year's game, our team decided to design, manufacture, and construct a mecanum drivetrain capable of holonomic movement. The main structure of the mecanum drivetrain consists of laser-cut plates, Gobilda channel, and Gobilda REX standoffs. The drive power transmission relies on external gearing and offset motors via a belt and pulley system. To transfer power between the motors and the wheels, two HTD 5mm belts and pulleys are used to achieve a final reduction of 18.5:1 off of four 13.7:1 Gobilda motors. The drivetrain pods have enough room to accommodate two parallel odometry pods on either side as well as one perpendicular odometry pod that sits in the middle of the drivetrain in between the crossbeam channels.

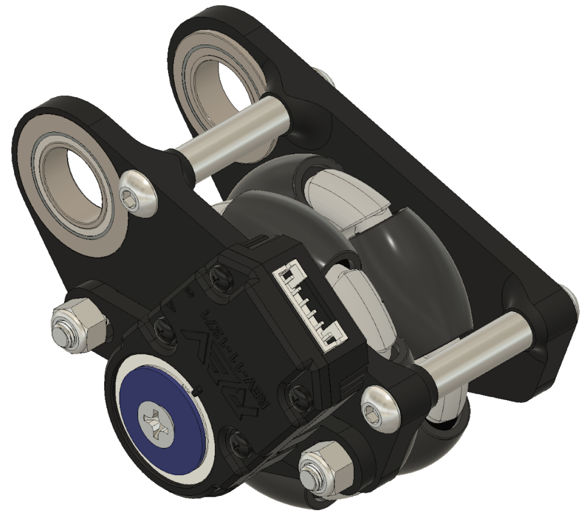
Odometry Pods	Versions 1.0 to 2.0



1. 0 Subsystem Description In FTC games, knowing the position of the robot on the field is very advantageous for many advanced autonomous and teleop programs and maneuvers. Three odometry pods exist on the robot: two are placed parallel to one another along the left and right sides of the robot, and one is placed perpendicular to the other two in the middle of the robot. Placing the wheels in this orientation allows the sensors to collect data about robot translation and rotation, accounting for both axes of movement in which the drivetrain is able to move. Each odometry pod consists of an omni wheel and a rotation sensor. On either side of the omni wheel sits a 3D printed plate with bearings that support a circular standoff that goes through the omni wheel and into the rotary sensor. This axle is constrained with 3D printed washers and button head screws with standoffs to separate the plates and ensure rigidity.

[1] More information on all mechanical subsystems and versions are available in our full Engineering Documentation notebook.

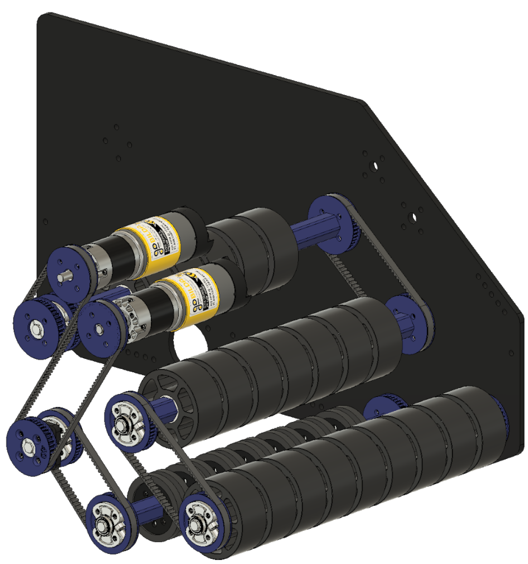
2.0 Subsystem Description After printing the required 3D prints for the v1 odometry pod, we found the circular shaft to slip often. To fix this problem, design team members decided to use an AndyMark omni wheel that had a 0.5” hex bore in the middle of the wheel to accommodate a hex shaft. The AndyMark omni wheel that we decided on had 35A durometer rollers; having experience with this compliant material from our SKYSTONE intake, we knew that the rollers would be very grippy and would get great traction on the field tiles. The new shaft was a 0.5” hex shaft 3D printed from PETG, and just like in the previous design, there are bearings at both ends of the shaft to support its movement and screws to constrain the shaft axially. Due to the larger size of the new omni wheel, modified versions of the module plates were designed to fit with the larger wheel radius.



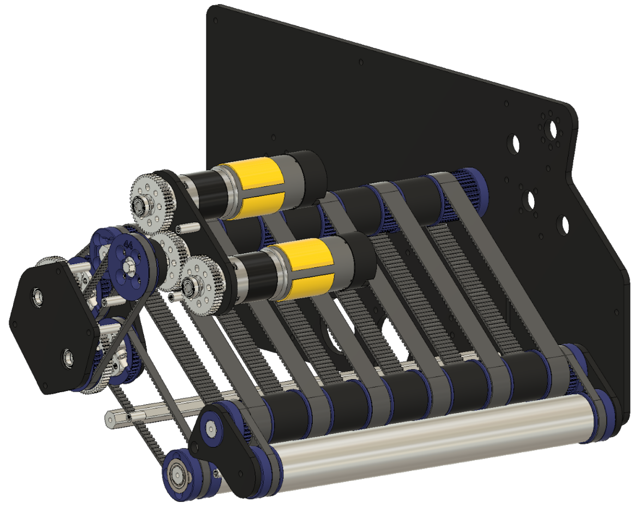
Intake	Versions 1.0 to 5.0

1.0 Subsystem Description To be able to transport rings from the field into our robot, we took inspiration from manufacturing and factory sites that used conveyor belts. To transport rings up to the hopper, we use a series of two stages of polyurethane flat belts from McMaster-Carr. The belts make contact with the top of the rings to initially push them into the intake and later carry them on an angled ramp towards the hopper. The intake uses a roller close to the ground (called a bottom roller) to feed the rings onto the ramp from the ground so that the rings have a powered mechanism to guide them on to the ramp rather than relying on the force of the conveyor belt system alone to push them onto an angled ramp. The power transmission system is based on a live axle setup that uses belts and pulleys. Each Gotube roller that supports the urethane belting is attached to a Gobilda 8mm REX shaft that rotates with the Gotube and belting system as power is applied to the mechanism through a motor. Using belts over a direct drive system also allows us to transfer power between multiple roller stages. The overall intake structure is mounted to the drivetrain inner plates through 3D printed mounts with holes for screws to secure the laser-cut intake bearing plates to the drive plates.

2.0 Subsystem Description First, we added a stage of AndyMark compliant wheels to the bottom of the intake such that these wheels would be the first to make contact with the rings when they are on the ground. Raised slightly below the height of a ring -- 0.75 inches off the ground -- the compliant wheels are positioned to conform to the shape of the rings and grip them to push them into the powered ramp and conveyor belt system. Instead of having a bottom roller kick a ring up onto a stationary ramp, we replaced the ramp system with what used to be the top-powered urethane belting conveyor system. This combination of wheels and belts meant that we would be able to both have continuous contact with the rings while they travel up the intake and use compliant wheels to conform to the ring shape to bring them into the mouth of the intake at the start. We also added a second motor to address a torque concern that we had about our initial intake version. Adding a second motor meant that we would maintain the fast speed of a 5.2:1 motor while doubling the torque of the system.



3.0 Subsystem Description After trying to weld urethane belts together, we realized that we lacked the proper tools to be able to make strong welds that would withstand the tension of our intake and the test of time. We replaced the powered ramp with a stationary ramp and a powered roller. However, to address the concern of our initial powered roller, we designed the roller to use 48mm disc wheels from Gobilda instead of larger AndyMark grip wheels. In keeping with the theme of compliant wheels on top of the intake to bring rings into the robot and transport them up the intake, we continued to use AndyMark compliant wheels, although we added a third stage and allowed the wheels/rollers to narrow as the intake went upwards, as the rings would need to be centered in the intake to properly line up with the shooter hopper. To accommodate the restructuring of the powered conveyor system, we moved the intake motors to face-mount to the inner left drive plate and designed a complex belt run system that kept with the theme of delegating power to the different parts of the intake -- one motor was delegated towards powering the bottom roller (which was required to spin in the opposite direction of the top compliant wheels) and one motor was dedicated to running the top compliant wheel rollers.

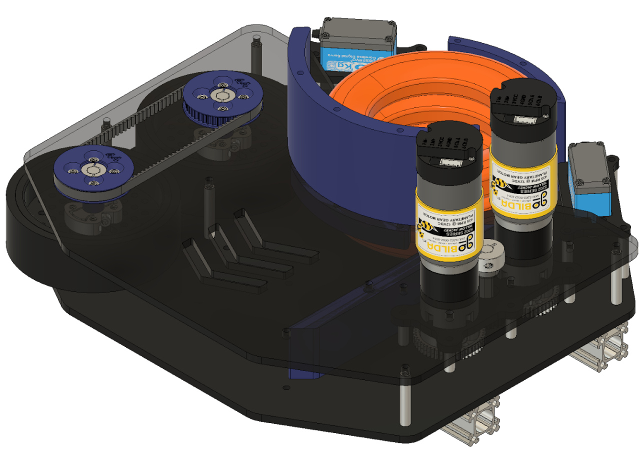


4.0 Subsystem Description The first major change in this intake version is the shift away from wheels in favor of timing belts and Gotube. The previous intake version required too many wheels that went over our budget for a single mechanism, and we knew we could increase the efficiency of the intake by condensing the system into one of fewer parts. In order to make initial contact with the rings on the ground, we wanted to have a system that mimicked the compression and form-fitting qualities of the compliant wheels, so we decided to design and manufacture a spring-loaded Gotube roller. Having the roller coaxially spring-loaded meant that it was able to rotate around the same shaft from which it's driven, meaning that when encountering a ring, the roller could move up and down to fit the form of the ring and provide just enough compression to bring the ring into the intake mouth and closer to the bottom roller. The new power transmission was created to consolidate the belt runs of the previous version while more equally distributing motor speed and torque. We added a 1:1 external gearbox that mechanically linked the intake motors as we found mechanical linkage to work well on our shooter, ensuring that motors were synced up and working as one unit.

5.0 Subsystem Description In this version, we switched to belts that did not use timing teeth to run, since previous versions exhibited improper center-to-center challenges that allowed belts to skip and the intake to run discontinuously and improperly. Deciding to switch to a premade, closed belt, we decided to switch to round belts from Gobilda. These belts were already in loops, could be stretched to attain the desired center-to-center distance, and are the right grippiness for our use case. To further simplify the power transmission and gearboxes, we decided to limit the use of timing belt in as many places as possible -- this meant replacing the secondary intake gearbox with only gears (a 60 tooth gear on the intake motors and two 48-tooth gears for the two intake stages) that we were able to mesh properly by considering the pitch diameter of each gear and securing the gears in place with laser-cut plates and standoffs. Now, the secondary gearbox directly powers the upper roller of the intake, and the upper roller powers the lower roller with a timing belt. This is the current working intake version.

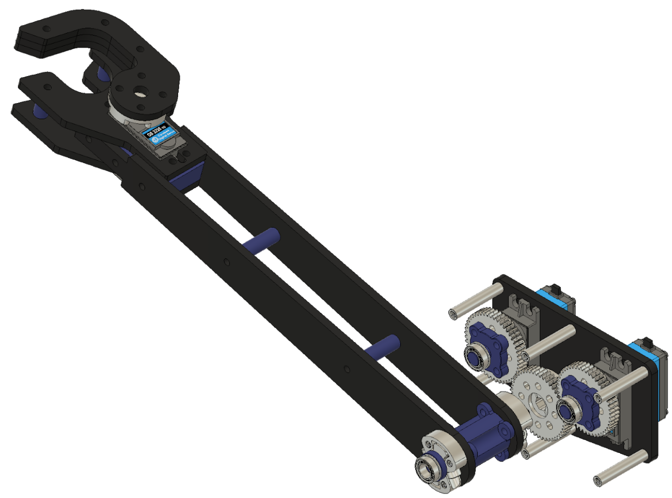
Flywheel	Versions 1.0 to 2.0

1.0 Subsystem Description In order to score rings in the tower, our team decided on using a flywheel system in order to precisely shoot the rings into each goal and to score powershots; we found that the best way for us to shoot straight and with power would be to use two high-speed wheels and compression of the ring on the other side. This system uses two mechanically-linked 6000 RPM 1:1 motors with a 1:2 reduction from the motor to the flywheel to power two Rhino wheels from Gobilda. The flywheel system that we use is also known as a dual inline flywheel. In this version of the flywheel, the rings are pushed into the rotating wheels. The wheel then pulls the ring in and the ring becomes pressed between the wheels and a wall on the other side. This pressure keeps the ring in contact with the wheels and moving quickly to the tower goal. To transfer the power from the motors to the wheels, we use spur gears and HTD 3mm belts, and 3D printed pulleys. The structure of the flywheel consists of various laser-cut plates and 3D printed parts. The laser-cut top and bottom plates, which are the main structures supporting the wheels and gearbox, have bearing holes and mounting holes. The rings sit in a “hopper” in the flywheel once they are finished passing through the intake, and a 2 bar linkage is able to translate rotational motion into oscillating linear motion to push the rings into the shooter.



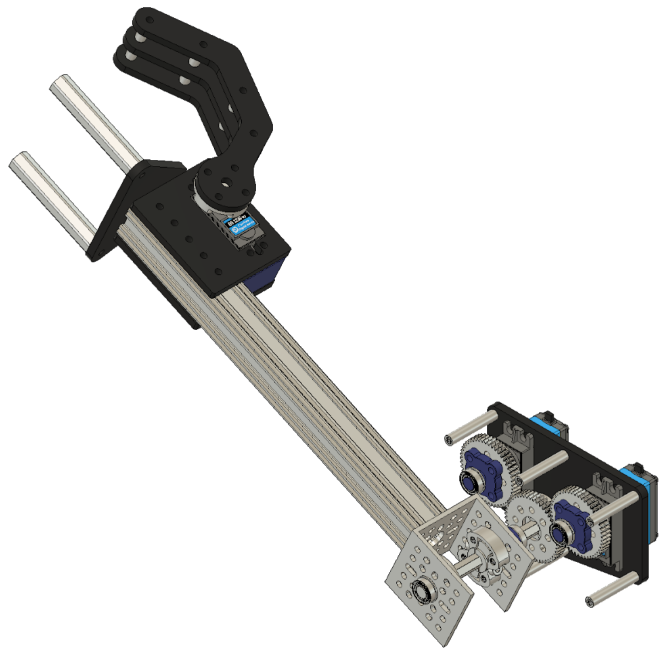
2.0 Subsystem Description First, we replaced the 3D printed structure that contained the gear reduction and motor mounting in the first version with a simpler laser-cut solution in this version. Now, two 1:1 motors (with 1:1 gearboxes -- not just the bare motors) are face-mounted to a laser-cut plate that has standoffs separating it from and mounting it to the bottom plate. In the middle of this plate lies a hole to mount a bearing which constrains the live axle that drives the main drive axle for the flywheel power transmission -- this axle has the 24-tooth pinion gear which is driven by two 48-tooth spur gears mounted to the two flywheel motors. This version of the flywheel uses the same overall power transmission structure: two motors with an external 1:2 gear reduction power a single live axle connected to a pulley, and this pulley drives another pulley--with a belt--that is connected to the first flywheel, and this first flywheel contains a second pulley to transfer power between itself and the second inline wheel. The main benefit of this new gearbox is rigidity and precision. Next, we decided to move to a simpler ring transfer system to move rings from the hopper into the spinning flywheels. Ultimately, we realized that a 2-bar linkage would not be able to move fast enough to push the bottom ring and retract before having the second ring fall down, meaning that rings could get stuck or catch on the mechanism. Instead, we designed a very simple 2-servo flicking system that has two servo horns attached to two servos, and when we are ready to fire a ring, both servos actuate and push the ring forward.

Wobble Arm	Versions 1.0 to 2.0



1.0 Subsystem Description We needed a way to move the wobble goal, and we decided that the most practical and the simplest way to accomplish this was with an arm and claw, one of the most fundamental mechanisms in robotics. We began with an arm that had a laser cut claw with a jaw that fit and guided the wobble goal into the hold of the arm. This arm uses two 35kg/cm servos to actuate the arm up and down and uses one 25kg/cm servo to open and close the claw. The two 35 kg/cm servos were placed in a 1:1 external gearbox with 48-tooth spur gears on each servo driving a 48-tooth spur gear on the output shaft. The gripper servo had a servo horn that allowed us to attach laser-cut fingers onto it that would wrap around the beam of the wobble goal. The finger component of the claw is wrapped in silicone tape to get a strong and sturdy grip on the wobble goal, as the friction from the tape prevents the wobble goal from sliding around or moving up and down while rotating the arm. The wobble goal arm acts like a human arm without the ability to bend at the wrist--it is a 2 degree of freedom arm. It has one axis of rotation at the base (where your elbow is), and the second axis is the claw where your fingers would be. The wobble arm can only move up and down and is actuated by the servo gearbox that is mounted to the top of one of the inner drive plates.

2.0 Subsystem Description Instead of using two parallel laser-cut arms, we replaced the bulk of the arm structure with Gorail, which is a lightweight aluminum extrusion that is much more rigid than laser-cut wood. Replacing the arm with Gorail meant that our arm would be able to sustain more force from unloading and reloading the wobble goal during matches, and we don't have to worry about snapping the arm in half if we run into a wall or another robot. In an effort to expand the margin of error that the robot and drivers could have when manipulating wobble goals, we restructured how the gripper works. Instead



of having a small arm and a small guide in which the wobble goal sits, we decided to switch to having a large arm and friction fit between the servo claw and the gripper structure; at the end of the Gorail extrusion sit two Gobilda REX standoffs spaced ~60mm apart from one another vertically. The space in between the standoffs is where the gripper on the claw servo moves into when the wobble goal is becoming secured in the gripper. The gripper begins opened, with about a 4-inch margin where the wobble goal beam can sit, and as the gripper claw closes, the wobble goal is drawn closer into the gripper, and the claw moves into the vertical space between the standoffs, securing the wobble goal between the standoffs and the claw as the servo closes and exerts a direct force on the wobble beam. As the wobble goal is lifted, the friction of the claw prevents the goal from slipping out of the gripper structure, and as an added safety net, the cap on top of the wobble goal catches on the gripper if the goal were to slide around while moving.

Software Engineering Summary

Odometry Localization and Path Planning

To perform complex autonomous movement trajectories and track real-time robot motion, we have devised and implemented a system of odometry, path planning, and path following for use in this year's ULTIMATE GOAL season within our drivetrain subsystem using the Road Runner library. In control theory, odometry is a way to perform robot localization via the use of rotary sensors; path planning and path following are systems of creating trajectories which a robot follows according to motion profiles and mechanical constraints of the drivetrain. Though our accuracy initially suffered while using drive wheel encoders, we were able to improve our code by using dead omni wheels instead.

To perform robot localization, we collect rotation data from REV encoders attached to unactuated omni wheels and transform that data into position data, calculating the forward kinematics of our mecanum-wheel chassis based on velocity. The control system receives velocity information from REV encoders in the form of ticks per second which can be easily transformed into inches per second; from calculus and physics, we can integrate velocity with respect to time to receive position information --

that is, we can numerically integrate the angular velocity of our dead omni wheels to gather information about each wheel's position as a function of time. Taking into account the physical location of each dead wheel on the mecanum chassis, we can perform forward kinematics to calculate and plot the center of the robot in real-time as the robot moves along the field. The three tracking wheels located on the robot chassis provide sufficient information to determine the x, y, and rotational velocity of the robot at each timestep. All of the operations mentioned to calculate the forward kinematics of the robot to plot its position are part of localization and are carried out by multiplying twist matrices that contain velocity information then integrating the elements of such matrices to achieve our desired output. As we sum the position accumulations together over time, we achieve the real-time position:

$$\begin{bmatrix} \frac{dx_{t+1}}{dt} \\ \frac{dy_{t+1}}{dt} \\ \frac{d\theta_{t+1}}{dt} \end{bmatrix} = \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 \\ sin(\theta) & cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{dx_t}{dt} \\ \frac{dy_t}{dt} \\ \frac{d\theta_t}{dt} \end{bmatrix}$$

To perform path planning, we use a technique called Hermite spline interpolation to generate a quintic spline from a list of waypoints. A quintic spline is simply a 5th degree polynomial of the form:

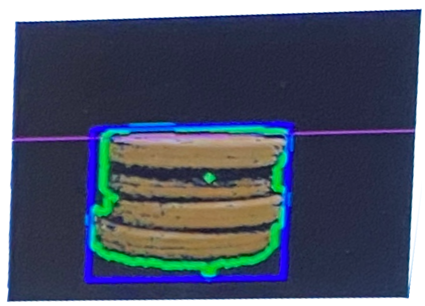
$$A^T A x = A^T b \qquad x(t) = a + bt + ct^2 + dt^3 + et^4 + ft^5$$

whose coefficients a through f can be determined by gathering user-defined waypoints and taking the derivative of the function, placing a system of 6 equations into a matrix, and solving the normal equations of linear regression to gather our coefficients that define a spline. This spline defines the 2D trajectory that our robot will follow -- in order to follow this spline and integrate our localization within our path planning to achieve consistent path following, we convert our spline to a parametric curve in 2 dimensions (a curve for the x dimension and a curve for the y dimension) such that our odometry is able to follow these functions independently and perform error correction.

After we have generated a spline to follow, we must actually follow the path; from calculus and physics, we are able to take the derivative of a position versus time function to achieve the function's velocity; here, we take the derivative of the two parametric Hermite curves to achieve the path's initial motion profile. As we mentioned earlier, we are able to receive velocity information from our REV encoders, so we can perform inverse kinematics on our drivetrain to follow the velocity of the Hermite spline using velocity data from our rotary sensors. Simply following the initial motion profile will lead to inconsistencies in path following, however, due to physical inconsistencies and imperfections. To make a closed-loop system that performs error correction, we utilize our localization algorithm to compare our desired position in time versus our actual position. To correct for any discrepancies between the real versus expected robot pose, we utilize two PID error correction loops, one for the translational component of the error and one for the heading component of the error; this PID loop corrects for the error in the robot pose by adjusting the motor powers such that the error is minimized as quickly as possible without oscillating around the setpoint (the expected pose). We're able to use our planning and execution capabilities during TeleOp to automatically align to a fixed point on the field for shooting.

Computer Vision Processing

To perform autonomous stack height classification, we utilize a Logitech webcam mounted to the robot and the FTCLib + OpenCV library for Java which enables fast image processing tools and matrix manipulation. All images can be treated as 3-dimensional matrices with each dimension being one of the RGB channels of the image whose size is determined by the camera resolution. Once we receive the image input frames, a blur filter is applied to the image to smooth out any curves and allow the stack to blend together more easily for further processing. Next, we search for pixels in the image that meet a certain threshold for the "orange-ness" of a pixel and take note of the pixels that meet the threshold.



We create a greyscale masked composite image of the pixels that meet the orange threshold and using OpenCV's contour feature, we can search for the largest continuous contour within the masked image to detect where in the image the rings are. Finally, we can calculate the ratio of the contour height to the camera's resolutions to develop a metric as to how many rings are in the stack. Based on this calculated ratio (taken at the end of initialization), we can confidently predict the number of rings in a stack in autonomous.

TeleOp Mecanum Driving

This year, our team moves around the field using a mecanum drivetrain; this type of chassis is capable of holonomic movement, meaning it can move in any direction in a 2D plane without changing the heading. To take advantage of this unique property of our drivetrain, we use trigonometry to convert gamepad input into velocity vectors that the mecanum drivetrain follows during TeleOp. Whichever way the user points the left joystick, the robot will go in that direction without turning. In addition to knowing which direction to go, the user also has to determine how quickly to drive. For example, if the user pushes the joystick slightly forward, the robot should drive forward slowly. But if the user pushes the joystick forward as far as it can go, the robot should drive at top speed. This is the magnitude of the joystick. The magnitude of the joystick is calculated by using simple trigonometry and the Pythagorean theorem ($a^2 + b^2 = m^2;\ m = \sqrt{a^2 + b^2}$). Treating the x and y coordinates of the joystick as legs of a right triangle, the magnitude of the joystick is the hypotenuse formed by these legs.

To determine the angle formed by the joystick, we can use more trigonometry–specifically, we can again treat the joystick x and y coordinates as lengths of legs of right triangles. Then, we can use the inverse tangent trigonometric function to determine an angle given two known side lengths. To compensate for angles outside the principal branch of the joystick bounds (between $\frac{\pi}{2}$ and $-\frac{\pi}{2}$ radians), we use Java's built-in inverse tan 2, or atan2, function. Next, to translate this information into motor speeds, we must then use the trigonometric sin function to adapt the joystick magnitudes and directions to motor powers. By plotting a few examples of motor powers required to move a given mecanum wheel forwards, backward, and diagonally at different angles, one can see that the motor power required to move a mecanum wheel resembles a graph of a translated sine function. So, by looking at the graph of motor powers vs direction, the front right and back left motors should be set to $sin(\theta - \frac{\pi}{4})$, and the front left and back right motors should be set to $sin(\theta + \frac{\pi}{4})$ in order to best model the behaviour of the direction vs speed graph. Finally, turning is simply done by getting the x position of the right joystick and inverting it to be intuitive to drivers.

Flywheel Error Correction

Our team decided to use a flywheel to shoot the rings using two 6000 RPM motors; we perform PID error correction on the shooter velocity in order to maintain a consistent angular velocity while shooting to hit our shots. A PIDF loop considers the error of the system, that is the difference between the desired and measured velocity, and applies adjustments to the motor powers in order to reach the setpoint. The output of a PIDF loop considers the error itself (to proportionally apply power to reach the setpoint), the derivative of the error (to reach the setpoint quicker), the integral of the error (not used), and a feedforward constant to account for any static friction in the system; using the output of Z to apply motor powers dynamically updates the shooter motor voltages to reach our desired velocity:

$$Z(e(t)) = kP * e(t) + kD * \frac{d(e(t))}{dt} + kI * \int e(t)dt + kF$$

Sustainability and Operational Plans[2]

Fundraising

Each year our team expects to raise about $7,500 in total from a variety of fundraising strategies. The money we raise goes towards sustaining our team, buying materials for our robot and outreach projects, and general operating expenses.

- **Corporate Sponsorships:** In order to acquire corporate sponsorships, we first research technology companies and local companies that we think would be willing to give to our team based on either their location or their vested interest in STEM education and technology. We then contact the company via email or phone.
- **Donations** This method is the simplest method for contributing to the success of our team. Since there is no joining fee to be a part of the Weber RamBots, parents of students on the team may donate to support the team.
- **School support:** At our school, every club is awarded $1000 from the school to use on club affairs and club matters. In 2019 our school opened a state-of-the-art fabrication laboratory which our robotics team uses almost every day for 3d printing, laser cutting, CNCing, and vinyl cutting. A part of this ongoing STEM education initiative is the Weber RamBots!

Sustainability Plan

In order for our robotics team to thrive and continue for years to come, we have implemented a sustainability plan to keep the team alive and well. Our sustainability plan includes recruiting new freshmen every fall to become members of our robotics team, as well as continuing to train lower classmen and younger students to become team leaders and knowledgeable members. As students join the team and learn what interests them, we conduct extensive, hands-on training in order to prepare them for leadership roles. Team members often take on more responsibility as they progress through high school while demonstrating expertise, empathy, and leadership.

Budget

Each year, our team creates a comprehensive budget that outlines the expected costs of materials, travel, and registration so that business members are appropriately targeted towards reaching a fundraising goal. Using this type of system lets all of our subteams see what resources are available and how we might go about dividing up these resources based on what the team needs and our financial status.

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[2] More information about our business team, fundraising, and sustainability / operational plans is available in our full Engineering Documentation notebook.