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Elevating and Scoring Mechanism Design for Mobile Robots

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MAKER: Elevating and Scoring Mechanism for Mobile Robots

Abstract

The VEX Robotics 2023-2024 game "Over Under" is a game where two teams of two robots each compete to score points within a 2-minute time limit. Robots must be able to score points both autonomously and with input from their drivers. Points can be scored by moving Reuleaux triangles, similar to rounded pyramids, under goals and elevating their robots off of the ground using a vertical pole, called the elevation bar. The objective of this project is to design and build an offensive robot that will be able to score a high number of points as efficiently as possible. This will be done by creating a well-rounded robot that can move and score Reuleaux triangles, referred to as triballs, as well as elevate off the ground at the end of the match. The robot will also be compact and lightweight so it can easily navigate the field. It must also be able to withstand minor collisions with other robots and the elements on the game field. The robot will feature an intake to move triballs, wings to push multiple triballs at a time, and a lifting arm with a claw to grab onto the elevation bar and lift off the ground. Most of the construction of the robot will be done using standard VEX parts, 3D-printed polylactic acid (PLA) parts, and milled aluminum and Delrin parts.

Need Statement

VEX Robotics provides a competitive challenge for students in STEM that allows them to solve problems and design robots with an engineering mindset. This year's challenge is called "Over Under" and is played on a square field that is 12ft by 12ft. A red and blue team consisting of 2 robots each must score plastic Reuleaux triangles, referred to by VEX as triballs, under their goals, and at the end of the match elevate their robots on a vertical pole. [1]. Each team has an offensive zone, which is half of the field. Triballs in the offensive zone are worth 2 points, and 5 points if they are under the goal. Elevation is separated into 3.6-inch-tall tiers from A to J. The robot in the highest tier gets 20 points, the second highest gets 15 points, and so on. Triballs cannot be removed from a team's goal unless both of the team's robots are on the same side of the field, which is referred to as double zoning. This encourages one robot specialized for offense, and the other specialized for defense. To have a high-performing robotics team, a high-quality and well-rounded offensive robot must be designed. The offensive robot should be able to achieve a high score by both scoring triballs and elevating higher than other teams. This robot's design and documentation will educate high school students and inspire them to pursue careers in STEM.

Objective

- The robot must be able to move triballs and score them underneath the net.
- The robot must lift itself off the ground by grabbing onto the side of a vertical pole.
- The robot must be lightweight so that it can move quickly and elevate itself effectively.
- The robot must be durable to be able to withstand impacts from opposing robots.
- The robot must work alongside a defensive partner robot designed by another division of the robotics team.

- The documentation of the robot must be easy to understand so that it can be used to educate high school students.

Background Study

VEX Over Under

The VEXU division is a competition for students enrolled in graduate and undergraduate programs. Each year, the game is the same as the one played at other grade levels, with some small rule changes. Every year, it is played on a 12ft-by12ft field. For VEXU teams, each match is played by two teams, each with two robots. One robot must start within a 24-inch cube, while the other must start within a 15-inch cube. The match begins with a 45 second autonomous period, where the robots must opperate without any input from the driver. The team that scores more points during the autonomous period is given an autonomous bonus, which is worth 8 points this year. The autonomous period is followed by a 1 minute and 15 second driver control period, and final scores are calculated after the driver control period.

For the “Over Under” game, the field is split into two offensive zones, with the drive team members of both teams standing across the field from their respective offensive zones. The offensive zones are separated by a 2.385-inch diameter polyvinyl chloride (PVC) pipe, referred to as the barrier [1].

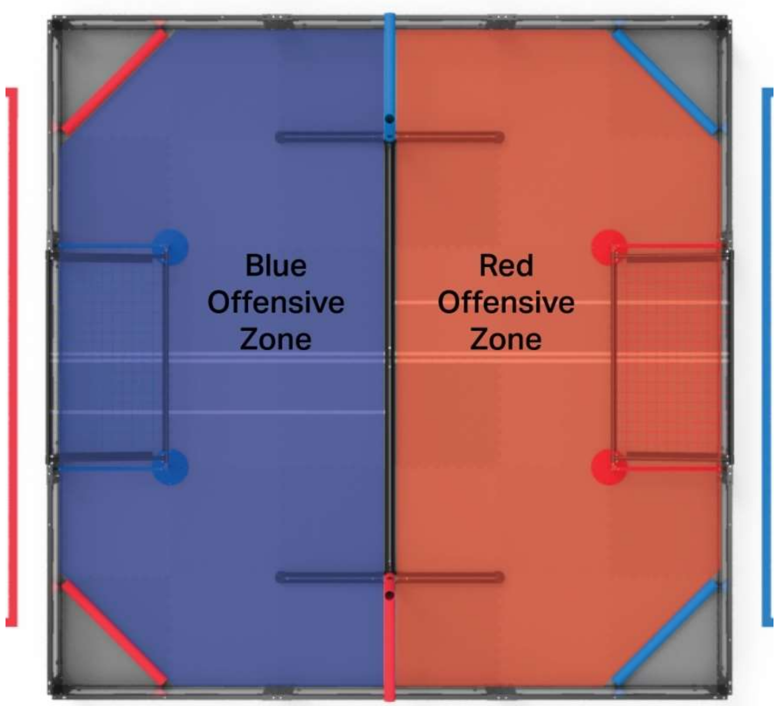

Figure 1: VEX Over Under field with offensive zones [1]

The main game element is the triball. Each team has two colored triballs, which count for them no matter where it is scored. Twelve triballs begin on the field, and each team is given twenty-two triballs that can be used as match loads. Match loads must be placed in the match load zones, indicated by colored PVC pipes in the corners of the field. To elevate at the end of the match, the robots must use the barrier or the elevation bar. However, should a robot contact the yellow cap on top of the elevation bar, it is not considered elevated [1].

Subsystems

Upon establishing the goals for the “Over Under” game, research was conducted to investigate similar mechanisms used for previous VEX games, as well as other “Over Under” robots. This research was to draw inspiration from other designs, while refining them to be consistent and efficient. An early idea for the robot included an elevation mechanism that could get into tier H, while lifting its partner robot above the elevation bar. This meant that the main mechanisms required for this project were a clamp to grab the elevation bar, a lifting arm to raise the robots off the ground, a system to raise the partner robot and elevate it, an intake to grab triballs, and wings to push multiple triballs at once. These subsystems were to benefit from the use of Proportional Integral Derivative (PID) control to complete their tasks. Since the defensive robot would handle match loads, a launching mechanism would not be needed for the offensive robot.

Lifting Arm

The most common type of lift used in VEX is called a bar lift, and there are several different variations. Bar lifts consist of a series of parallel bars or c-channels where one bar is fixed, and the others can pivot about joints [3]. The basic version of this is called a 4-bar and consists of two sets of parallel bars [3]. The end of a 4-bar lift moves in a circular path, and the range of movement is determined by the distance between the top and bottom bars [3]. The maximum range is close to 180 degrees, since the bars cannot pass through each other.

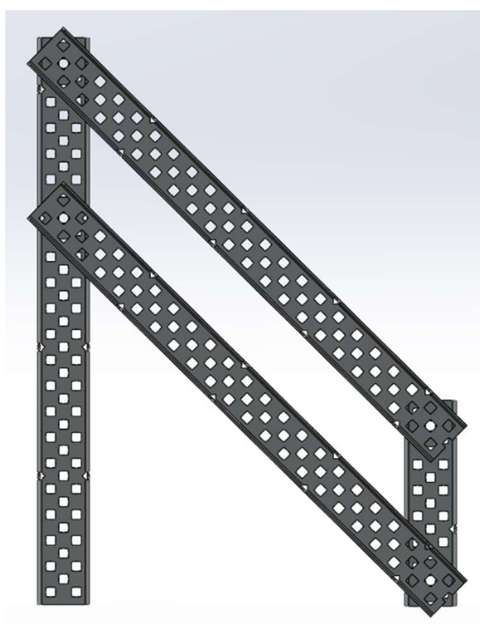

Figure 2: Structure of a 4-Bar Arm

Other variations of this design such as 6-bar or 8-bar lifts use the same principles as 4-bars, but each additional set of bars allows for a larger lift while folding into the same amount of space [3]. This can allow for a lower profile while collapsed but comes with the cost of added weight.

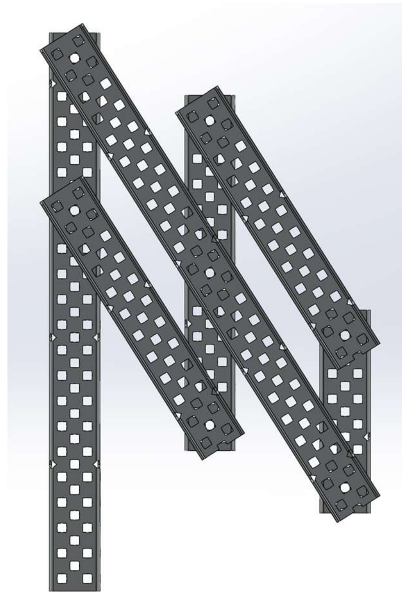

Figure 3: Structure of a 6-Bar Arm

The arm can be powered by either pistons or motors. Pistons would be faster and lighter but have a limited range of motion. Motors would be slower and heavier but have 360 degrees of potential movement and can use gear ratios to increase power. Table 1 lists the advantages and disadvantages of the two hardware implementation options.

Table 1: Comparison of Lifting Arm Hardware

Hardware	**Advantages**	**Disadvantages**
Pistons	• Fast • Light • Powerful	• Limited motion • Expensive • Delicate
Motors	• Full range of motion • Flexible torque using gear ratios	• Slow • Heavy

Actuating Ratchets

When considering a motor-powered 6-bar, the issue of the robot losing power was brought up. When the robot was disconnected, and the motors could no longer hold their place, the weight of the robot would cause the arm to extend, lowering the robot back to the ground. A way to prevent this was to implement a ratchet on the gears of the arm to stop it from rising. However, the arm needed to rise to be able to grab onto the elevation bar. To work around this, the ratched could be pneumatically actuated. As usual, rubber bands would pull the ratchet into the gear, but for most of the match, pistons would pull the ratchet away from the gears, allowing the arm to have a full range of motion. Then, when the robot began elevating, the pistons would release, allowing the ratchets to engage.

Clamp

There are many possible design approaches for the clamping mechanism. One approach involves using silicone wheels, referred to by VEX as flex wheels, because of their strong grip. They can be attached to the robot perpendicular to the ground and spun along the surface of the elevation bar, lifting the robot up the bar [6]. The weaknesses of this design are that it is slow and difficult to raise the drivetrain to be above or in line with the clamp itself. Raising the drivetrain is necessary to keep the robot in the highest elevation tier possible, since the tier is determined based on the lowest point of the robot. Another clamp design is a claw that grips onto the bar. This design can be made circular to create a firmer grip. The main concern of this design would be how to power it. It can use a motor, pneumatic pistons, or a passive latch mechanism. Motors are commonly used by many teams for claws because they can be easily implemented onto the robot. However, they can be slow and lose some of their grip when the match ends and the robots are powered off, which could cause the robots to fall. Pistons have a strong grip that will not weaken after the match but require a large amount of space to fully actuate. The passive locking mechanism can create a strong grip and will not weaken when the robot loses power. Another benefit of this design is that it saves space and weight, as well as a wire port on the brain since it does not need to be powered. The primary drawback of this design, however, is that it cannot be released if it closes prematurely during the match.

Table 2: Comparison of Clamp Approaches

Design	**Advantages**	**Disadvantages**
Flex Wheels	• High amount of friction	• Slow • Difficult to mount low on the robot
Pneumatic Clamp	• Strong grip • Quick activation • Light	• Requires a lot of space
Motorized Clamp	• Good grip • Small space required	• Slow • Loses grip after the match
Passive Clamp	• Light • Does not need a port on the brain • Will not loosen	• Tight closing tolerance • Grip only as strong as the material

Robot-Raising Mechanism

A mechanism to lift one robot above another one is not very common so there are not many examples to refer to. However, the VEX game “Nothing but Net” awarded points for lifting a robot fully above the other. One mechanism used for this was a lift powered by rubber bands and held in place by pistons [4]. The system consists of a sturdy frame with rubber band attachment points that support the robot's arm while movement takes place. The lifting platform is moved by vertical rails that resemble scissor lift mechanisms. The partner robot would drive onto the lift and the pistons would be released, and the rubber bands would contract and lift the robot up. Pneumatic lift mechanisms and rubber band tension lifts are two common robotics methods for vertical mobility. Potential energy is stored by rubber bands, whereas compressed air is used in pneumatic systems. Both need to be carefully designed for dependability and minimal upkeep. Pneumatic systems do, however, have issues with periodic tank refilling and speed regulation. This method can be applied here, and a smaller-scale system can be designed to raise the partner robot into the higher elevation tier. The main consideration for this would be making sure there is enough space in the drive train for the partner robot to fit. Another raising mechanism used in “Nothing but Net” was a deployable ramp that the partner robot could drive up [4]. A latching mechanism can be used to keep the partner robot in place as it is raised. This design is slower, but much more mechanically simple than the rubber band lift.

Table 3: Comparison of Raising Mechanism Approaches

Design	**Advantages**	**Disadvantages**
Rubber band lift	• Strong • Fast	• Requires a wide drivetrain • Requires pistons • Mechanically complex
Ramp	• Can be passive • Lighter • Mechanically simple	• Angle must be considered • Slower

Intake

In VEX games, an intake is any system that can bring a game element, such as triballs, into the robot. According to the game manual, "a robot is considered to be possessing a triball if a robot’s change in direction would result in controlled movement of the triball”. Possession is limited to one triball at a time. This means that an intake only needs to hold onto a triball to move it around the field, rather than carrying it into the robot. Therefore, there are two main alternatives for an intake. The first is a rubber band roller, which consists of several rubber bands stretched between two sprockets or wheels. This has the advantage of applying variable compression to the triball, ensuring a secure grip. However, the rubber bands lose their elasticity over time. Additionally, they do not transfer torque well, meaning it would be difficult to push triballs under the goal. The other intake is a flex wheel intake. Flex wheels are silicone wheels that would be placed along a shaft. This intake has a good grip and applies torque well, making it easy to put triballs under the goal. The drawback is the compression is less variable than the rubber bands. This can be compensated by mounting the intake on a pivoting joint.

Table 4: Comparison of Intake Mechanisms

Design	**Advantages**	**Disadvantages**
Flex Wheels	• Good grip • Transfers torque well	• Invariable compression
Rubber Band Roller	• Good grip • Variable compression	• Poor transfer of torque

Wings

Since the possession limit is one triball, it would be illegal to grab and score multiple triballs at once. However, scoring triballs one at a time would be very inefficient. To get around this, a large flat face of the robot could be used to push triballs across the field and into the goal. Pneumatically actuated plastic panels, referred to by VEX teams as wings, can be used to increase the surface area for pushing. The pistons allow the wings to begin along the sides of the drivetrain before pushing outwards. This means the robot can fit within tight spaces, only expanding the wings when needed.

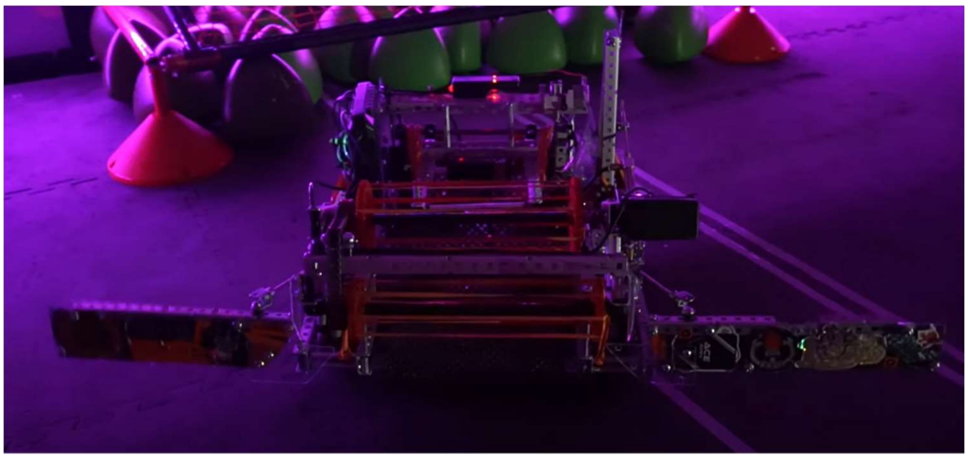

Figure 4: Example of wings on a high school robot [7]

PID Control

To ensure that the robotic systems can efficiently and precisely complete their task, a thorough analysis of the control system is vital to deliver the desired system responses. PID control is a closed-loop controller with three feedback components: proportional, integral, and derivative. These components make use of the difference between the current state and the desired state, referred to as error. The output from the proportional component is the current error multiplied by the given proportional constant kP giving an output that decreases as the desired state is approached. The output from the integral component is the cumulative error of the system multiplied by the constant kI typically increasing the output. The output from the derivative component is the difference of the previous error subtracted from the current error over the change in time between the readings and then multiplied by the given proportional constant kD. The derivative output during the controller's rise time is typically negative and thus decreases the output.

VEX Namespace

The VEX namespace is a library created by VEX Robotics to program V5 Electronics plugged into the V5 brain and is included in the VEX Visual Studio Code Extension. The VEX namespace has classes that represent each component such as motors, pneumatic solenoids, and inertial sensor that can be plugged into the V5 brain. Objects of the motor class can also act as a parameter for the motor_group class allowing for simultaneous control of multiple motors. While most electronic components need only one parameter being the port they are connected to, motors need 3 being the port number, the gear ratio, and whether a motor should be spin opposite the printed direction when given a positive spin value.

Engineering Requirements

The robot should meet the following engineering requirements:
- Must weigh 14.5 pounds or less.
- Must elevate at least 10.8 inches off the ground, reaching tier C.
- Must be able to push triballs over a pipe 2.385 inches in diameter.
- All systems must be powered with battery operating at a maximum of 12V.
- Must supply at least 14.5 ft-lbs. of torque.
- Must be able to restrict its size to fit within a 24-inch cube.
- Cannot expand further than 36 inches point-to-point.

Constraints

A. Pneumatics

Any Pneumatic tanks used can only be pressurized to 100 psi and stored in tanks rated for a minimum of 100 psi. Any form of air compression on the robot to repressurize the tank during a match is not permitted. These pneumatic components may not be altered from their original state with a few exceptions as follows:
- Cutting pneumatic tubing to a desired length
- Assembling of the components using pre-existing threads, brackets, or fittings
- Minor Cosmetic Labels

B. Electronics

Any additional electronics or sensors must be wired to the VEX brain and cannot directly interface with motors or solenoids. The additional electronics can only be powered by the VEX battery or a single additional battery pack. This additional battery pack must operate at a maximum of 12 volts. Low power motors not used for processing or sensing may be used, allowing an additional electronic such as a cooling fan for a microcontroller or a sensor that spins to take its reading. However, a commercial motor used to power a drivetrain or other kinds of movement on the robot is not permitted.

C. Custom Parts

There are many processes by which custom parts can be manufactured according to VEX rules, these include
- Additive Manufacturing (ex. 3D Printing);
- Subtractive Manufacturing (ex. Machining, Cutting, Drilling, Routing);
- Bending (ex. Metal Sheets, Thermoforming);
- Molding (ex. Silicone into molds);

- Attaching materials to each other (ex. Welding, Chemically Bonding);

D. Size

The robot must be able to restrict itself to fit inside of a cube with dimensions of 24” x 24” x24” and not expand to any state in which it does not remain within the boundaries of a 36” diameter cylinder with unrestricted height.

Standards

The elevation robot will be built and coded mainly using VEX Robotics hardware and software. The robot will incorporate:

- All parts used in the robot’s design along with the design itself must be following competition rules.
- The robot’s programming will be done using the ISO/IEC 14882:2020 C++ language in the VEX Code V5 extension of Microsoft Visual Studio.
- Wireless Communication made throughout the robot will be done through Vex Link. Vex Link is the communication standard created by VEX Robotics using a 2.4-2.4835 band.
- ASME Y14.5 – 18 standard for SolidWorks 2023 Student Edition
- Unit measurements follow the NIST HB 44-2023 standards for U.S. Customary Units.

Alternative Designs

Lifting Arm

When deciding which design to use for the lifting arm, the main decision was whether to power the arm using pistons or motors. To determine which design to use, the criteria considered were weight, speed, and range of movement. Strength was not considered because the system is required to be able to create enough power to lift both robots. When evaluating these criteria, it was realized there was no point on the arm for the piston to be mounted that would allow for a full range of motion. A set of linkages to move the arm using pistons and linkages would quickly become complicated with several potential points of failure. Therefore, the piston approach was disqualified, and the motorized alternative was selected.

Clamp

When evaluating which clamp design to use, four main criteria were considered. They were weight, grip strength, speed, and reliability. A Pugh Matrix was used to compare the alternative approaches based on these criteria. Weight was evaluated as the weight of the power method itself, since the main body of the clamp will weigh roughly the same for all three designs. It was given an important weighting of 30 because it is important to keep the weight of the robot below the specified range. Grip strength was evaluated as how strong the system can grab onto the elevation bar. It was given an importance weighting of 35 because it is very important that the clam is strong enough to support the weight of both robots, otherwise they will fall and not be considered elevated. Speed was measured by how long it took the given design to go from the open position to the closed position. Speed was given an importance weighting of 20 since it is important to elevate as quickly as possible, but not as important to the constraints of the robot as strength and weight are. Finally, reliability was considered as how consistent and durable the system is. It was only given an importance weighting of 15 since low durability can easily be compensated for by checking the system for signs of damage after every match.

Since there was no baseline for the Pugh Matrix, the alternatives were compared on how well they fit each criterion. The alternative that fit it the best was given a 1, the worst alternative was given a -1 and the final alternative was given a 0. The totals were then calculated and compared to determine the best approach.

Table 5: Clamp Pugh Matrix

Criteria	Importance Weighting	Piston	Motor	Passive
Weight	30	0	-1	1
Strength	35	0	-1	1
Speed	20	1	0	-1
Reliability	15	1	0	-1
Total		35	-65	30

For weight, two pistons were weighted for the piston alternative, since one would be needed for each side of the clamp. Together, they weighed 0.175 pounds. For a motorized clamp, either one or two motors could be used. One motor weighed 0.320 pounds, and two motors weighed 0.665 pounds. To evaluate the weight of the passive system, the lever and latches were weighed. Altogether, they weighed 0.025 pounds. Therefore, the passive system got a 1, the pistons got a 0, and the motors got a –1.

For strength, the passive system was given a 1 because unless the part breaks, the lock cannot open on its own. The pistons and motors were close in terms of strength. The deciding factor was that motors cannot hold their position after the robot loses power, but the pistons can. Therefore, the pistons were given a 0, and the motors got a –1.

For speed, the time for each mechanism was measured five times and then averaged. The pistons took 0.26 seconds to close on average. The motor took an average of 1.08 seconds to close. The passive system got stuck often because the lever had to be very tight to the elevation bar, causing an average time of 2.14 seconds. Therefore, the pistons were given a 1, the motor was given a 0, and the passive system was given a –1.

For reliability, all three systems used similar designs for the claw itself, so there was no significant difference in the durability of the claws. The passive system was the least reliable because of the issue with lever getting stuck. The pistons and the motor were equal in their consistency. However, the motor's grip loosened when the robot lost power, so the pneumatic system was deemed better. Therefore, the pistons were given a 1, the motor was given a 0, and the passive system was given a –1.

After totaling and comparing the scores, the piston-actuated claw was determined to be the best approach.

Intake

When analyzing the alternative intakes, the decision was straightforward. Both the flex wheels and rubber band rollers had good grips on the triballs, and the lack of variable compression of the flex wheels could be easily compensated for by mounting the system so that it could pivot. However, the rubber band roller took longer to score the triball in the goal. Since the driver-control period is so short, efficient use of time is crucial. Therefore, the flex wheel intake was chosen as the better method.

Robot-Raising Mechanism

For the raising mechanism, the two designs considered were a rubber-band lift, and a ramp. There was no need for a formal decision process, since it was identified early on that for the 15-inch robot to be able to fit onto the rubber-band lift, the 24-inch robot's drivetrain would need to be too large to easily maneuver around the field. When designing the ramp, the main things to consider would be its size, the ability of the other robot to drive up it, and its ability to hold the partner robot in place.

Project Cost Analysis

Mechanical Design

Design Strategy

At the regional competitions, the team realized speed was very important for pressuring the other team. Because of this, the new design was focused was improving the speed of all the robot's subsystems. Additionally, to fully dedicate the team's attention to the development of the subsystems, one design would be made and both robots would be copies of each other. This meant both robots needed to be able to retrieve match loads and elevate well to compete at a high level.

Subsystem Designs

Drivetrain

The new drivetrain was made using custom Delrin plates instead of c-channels because holes could be placed where they were needed rather than at the half-inch intervals on the c-channels. This allowed for greater flexibility when designing the gear train and allowed for larger holes to be used to mount ball bearings, which would greatly reduce the friction on the drivetrain. Delrin was selected as the material for the drivetrain because it is lightweight, durable, and has excellent impact resistance, which will allow it to withstand collisions with other robots.

Like the previous version of the drivetrain, the new one features eight 600 rpm motors. However, the motors were connected to the wheels using a 1:1 gear ratio, meaning the drivetrain would be nearly twice as fast as the previous version. The new drivetrain also had four wheels on each side because it provided better traction and ensured that two wheels would always be in contact with the barrier when driving over it. To leave room for the intake, the motors were all placed on the back of the drivetrain. Because of this, two motors on each side connected directly to the back two wheels, and the other motors were placed above them with gears connecting the shafts.

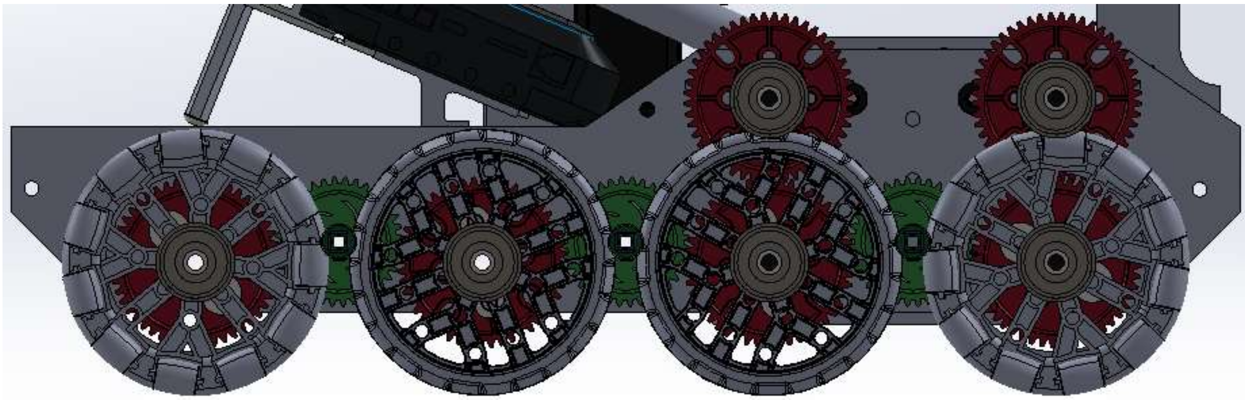

Figure 5: Drivetrain Gearing

The main challenge with designing the drivetrain was connecting the two sides while accommodating the space necessary to drive over the short barrier. The barrier is 2.38 inches in diameter, and it is raised slightly so that the top of the pipe is about 2.5 inches above the ground. This takes up a significant amount of space in the center of the drivetrain. Because of this, having a connecting plate across the bottom of the drivetrain was impractical since there would not be adequate space to mount anything onto it. To get around this, the connecting plate was put at the top of the drivetrain. This came with the challenge of supporting the plate so that the center of it did not bend down. Another plate was added underneath it for support, with a cutout for the barrier. Additionally, several 3D-printed braces were used to support the drivetrain.

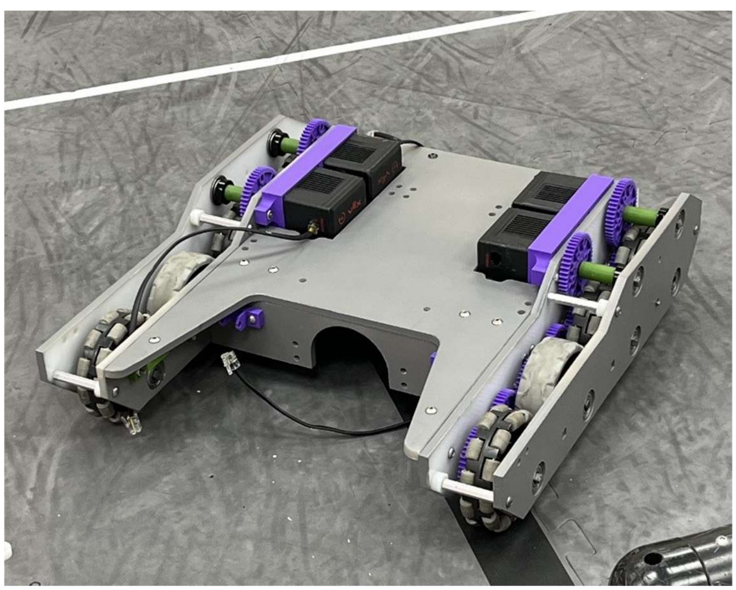

Figure 6: Assembled Drivetrain

To ensure that the robot would be able to withstand competition, simulation tool in SolidWorks was used to analyze the structural integrity of the drivetrain. The drivetrain plate was tested by simulating the robot crashing into a wall. The final robot weighed 16.5 pounds, so assuming it was moving its top speed of 7 ft/s and came to a full stop in half a second, it would experience a force of 7.18 pounds. The force was applied to the front face of the plate, and the rear face was fixed. This was done to generate the most extreme examples of stress possible in the part.

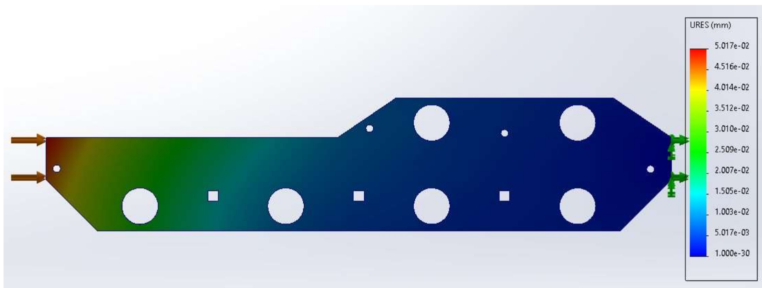

Figure 7: Displacement of Drivetrain Plate

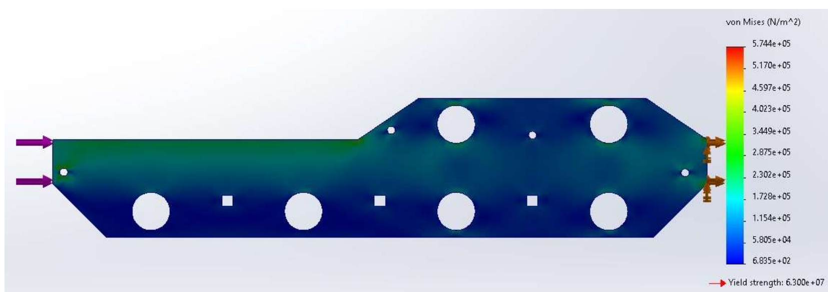

Figure 8: Von Mises Stress of Drivetrain Plate

As shown in the figures above, the drivetrain was able to withstand the impact very well. The maximum stress experienced is well below the yield stress of Delrin, only reaching approximately 0.46% of the yield stress with no visible or plastic deformation. Such a significant gap between the expected stresses and the allowable stress was required because the drivetrain would be repeatedly impacted throughout the competition, with forces of an unknown magnitude. This was because the exact size, weight, and speed of opposing robots were unknown prior to the competition. Additionally, there was not enough material to make extra pieces for the drivetrain, meaning the plates could not fail.

Intake

Intake used the same core design as the last version, but it was made to be faster and have more power. A second motor was added to prevent the intake from overheating, and the 600 rpm motors were connected to the shaft using sprockets with a 2:1 ratio, resulting in a speed of 1200 rpm. This was done so that the intake would be able to quickly grab onto a triball regardless of its orientation. Underneath the intake, a polycarbonate sheet was attached on two hinges. The hinges allow the flap to rise above the short barrier when the robot goes to elevate. Rubber bands were used to keep the flap lowered throughout the match so it would always be able to intake.

Figure 9: Intake

Wings

The goal for the wings was to be able to get match loads as well as push triballs into the goal so that fewer total subsystems were needed. To do this, the wing was made to extend into the match load zone, knocking the triball out as it moved. However, the wing pushed the ball into the wall too much, meaning it would not move over the barrier. Adding an angle to the wing fixed this issue but caused the wing to be out of the 15-inch size limit. A 3D printed wing was made that had a smaller and more accurate angle. This worked better but was still not very consistent. The other issue with this design was the pistons would be pushed back when trying to push triballs into the goal, meaning it was unable to score them.

Figure 10: 3D Printed Wing

To fix the issue with the wings, they were mounted so that they began vertically and were then pushed horizontal by the piston using a hinge. This was much stronger at pushing since the piston could not be lifted back up by the triballs. This new design could not hit match loads while extending but could still retrieve match loads. It does this by driving back and forth, hitting the triballs as it moves, which worked consistently.

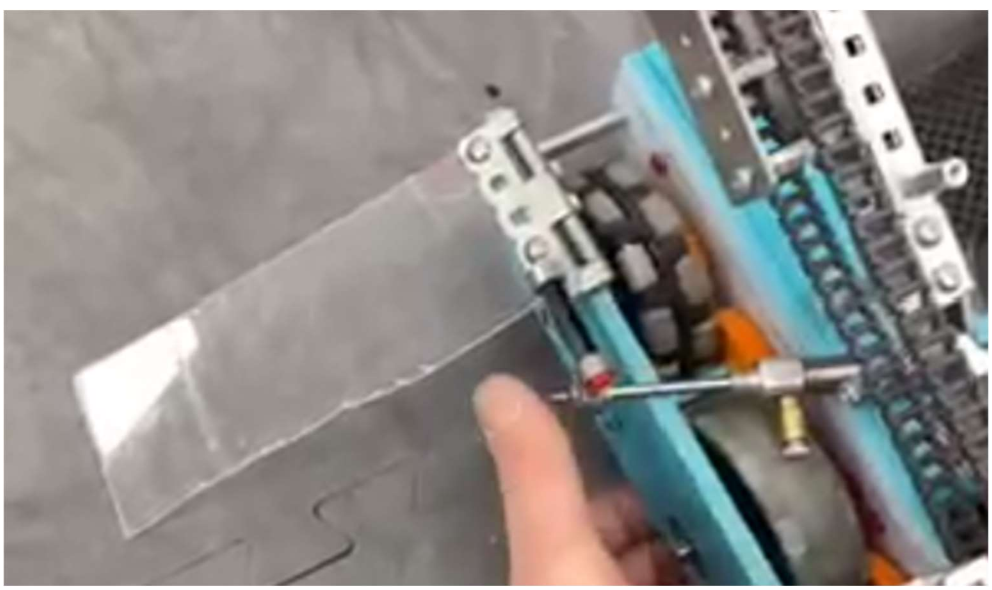

Figure 11: Horizontal Wing

Elevation Mechanism

The biggest change for the final iteration was the elevation mechanism. The 6-bar arm was slow and took up a large area on the robot. To address this, the new arm was made to be a single arm that would pivot on a point at the back of the robot. It would begin horizontally over the top of the robot, then be moved vertically using a piston. A piston with a 6-inch stroke with 25 lbs of force at 100 psi was mounted between the arm and the drivetrain. Using a weight of 16.5 lbs and an estimated 3.9-inch distance between the center of gravity and point of rotation, the required torque was calculated to be 5.36 ft-lbs. Dividing this by the force generated by the piston, it was determined the piston had to be mounted at least 2.57 inches away from the pivot point.

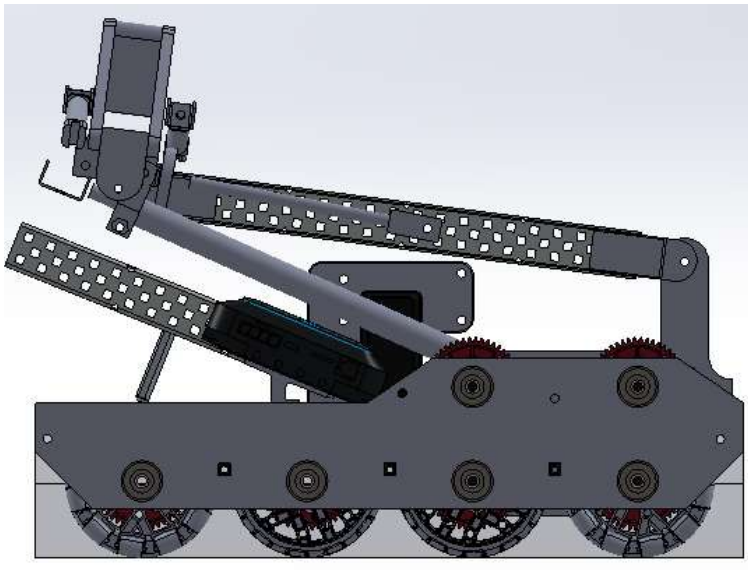

Figure 12: Collapsed Elevation Arm

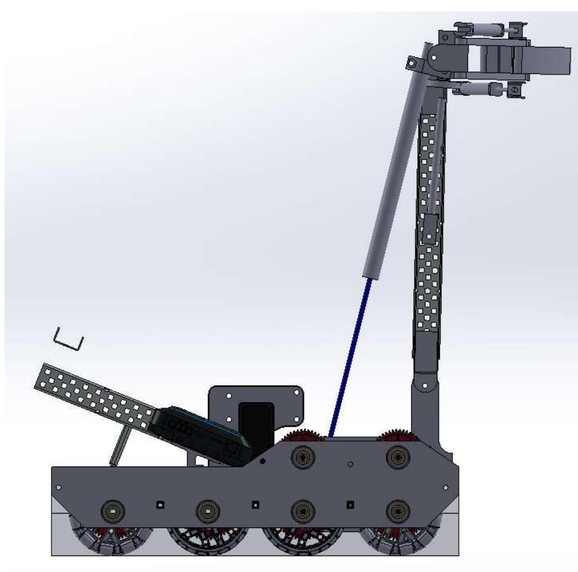

Figure 13: Raised Elevation Arm

The claw also had some significant changes. First, the claw was made to only be 260 degrees when closed so that it could be lower profile when open. The claw was designed to be flat when in the open position, and two single acting pistons were used to actuate it. Each side of the claw had a latch that used rubber bands to hold the claw closed after the robot loses power. A __ inch thick sheet of silicone was attached to the inside of the claw using epoxy, which stopped the claw from sliding down the elevation bar. The last change on the elevation mechanism was a “wrist” mechanism that would make the claw go from perpendicular to the arm to being in line with it. This would result in the robot being upside down, sticking out perpendicularly from the elevation bar in Tier E. Having both robots in Tier E would be better than any team had done prior to the world championships. The pistons to be used for the wrist also generate a force of 25 lbs, but only have a 4-inch stroke. It was calculated that to lift the robot, the piston would need to apply its force 5.8 inches away from the point of rotation. This would not be possible since the furthest point on the claw was only 3 inches from the pivot point. However, two pistons could be used to add to the required force. The pistons were placed along the arm and began extended. They were connected to the front of the claw using strings and pulled on the strings when retracted. After testing this design however, the pistons were unable to create the desired motion in the wrist. A new version using pulleys was made to change the direction of the force more effectively, but this was also unsuccessful. The claw itself, however, was consistently able to grab and lock onto the elevation bar.

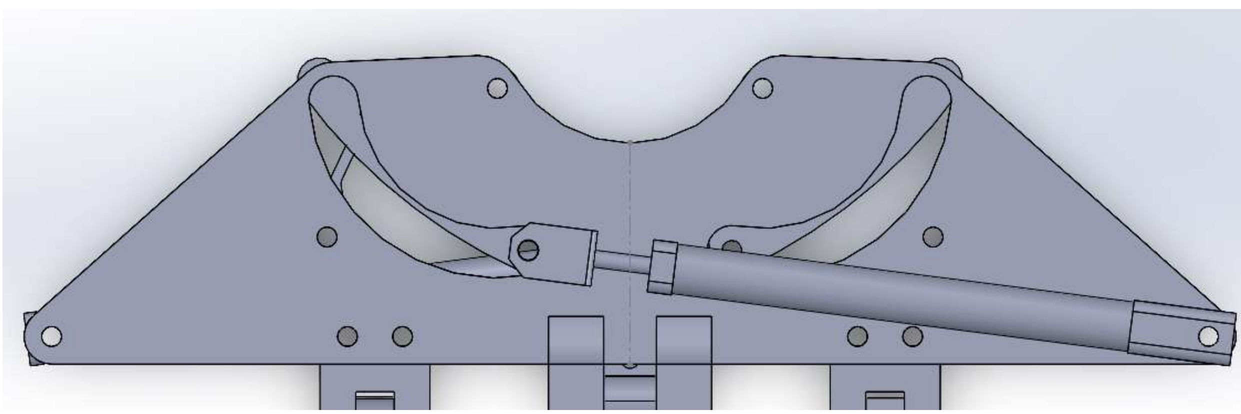

Figure 14: Open Claw

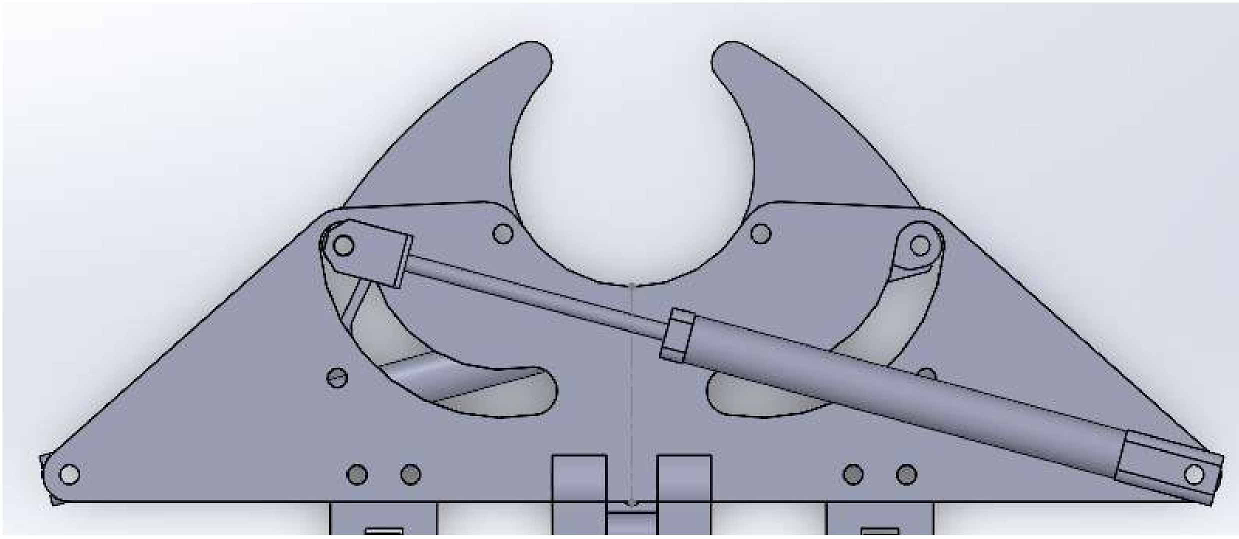
Figure 15: Closed Claw

Since the wrist mechanism did not work, the robot would only be capable of reaching Tier B. While this would not be significantly behind most teams, it would not be enough to provide an advantage. Therefore, the elevation arm was altered slightly to reach Tier C. This was done by raising the point of rotation further from the ground. After this change was made, the large piston initially used for the arm was not able to fit on the robot in a position that would provide sufficient torque. Instead, the two 4-inch stroke pistons from the wrist were used. With the center of gravity now being about __ inches from the center of rotation, it was calculated that the piston would need to be mounted __ inches from the pivot point. Due to the space available on the robot's drivetrain and the angle at which the piston's force needed to be applied, it was not possible to mount the piston sufficiently far from the point of rotation. To address this, a second piston was added, which had the added benefit of extra stability and redundancy in case one of the pistons did not provide its full force.

After testing the lifting arm, the drivetrain would lift above the ground, but there was a significant angle between it and the elevation arm, and the robot would only be in Tier A. To lift the drivetrain to its proper position, a winch was added to the arm, using a 200-rpm motor directly driving the shaft. String was then tied between the drivetrain and a collar on the shaft. A ratchet was used to prevent the drivetrain from lowering again once it was raised. After testing, the winch was able to fully lift the drivetrain in 3 seconds.

When the robot was raised, the claw would tilt off the elevation bar slightly, resulting in the robot being in Tier B. This was fixed by lengthening the ends of the claw to create a 320-degree grip. An extension was also added to the bottom plate of the claw to stop it from being able to rotate. These adjustments were successful and the robot was able to consistently elevate into Tier C.

Software Design

VEX Namespace

The VEX namespace is a library created by VEX Robotics to program V5 Electronics plugged into the V5 brain and is included in the VEX Visual Studio Code Extension. The VEX namespace has classes that represent each component such as motors, pneumatic solenoids, and inertial sensor that can be plugged into the V5 brain. Objects of the motor class can also act as a parameter for the motor group class allowing for simultaneous control of multiple motors for example the

PID Functions

For the autonomous portion of the competition a robot must have at least two basic functions, one to drive a specified distance in a straight line, and another to turn to a specified heading accurately. With these two functions it is possible to move to any location on the game field and develop a variety of autonomous routines. To ensure quick and accurate movements PID controllers were used in both functions.

```
driveSpeed = (kp*error + ((kd*(error - errorPrev))/dt) + ki*errorSum); // PID Speed controller
```
Figure 16: PID Controller

Drive Distance PID Control Function

The function drivePID was created to drive a specified distance accurately and quickly. The function is called with an input of the desired number of inches the robot should drive forward with respect to its heading, the function also accepts negative numbers to allow for the robot to drive backwards. The error is then set to the input desired number of inches and the encoders are refreshed every 50ms. From the encoders the number of rotations in the motor is taken and multiplied by the gear ratio to find the number of rotations of a drivetrain wheel and the number of wheel rotations is multiplied by the circumference to find the distance traveled which is then subtracted from the current error. This loop repeats until the absolute value of the error is less than a half inch.

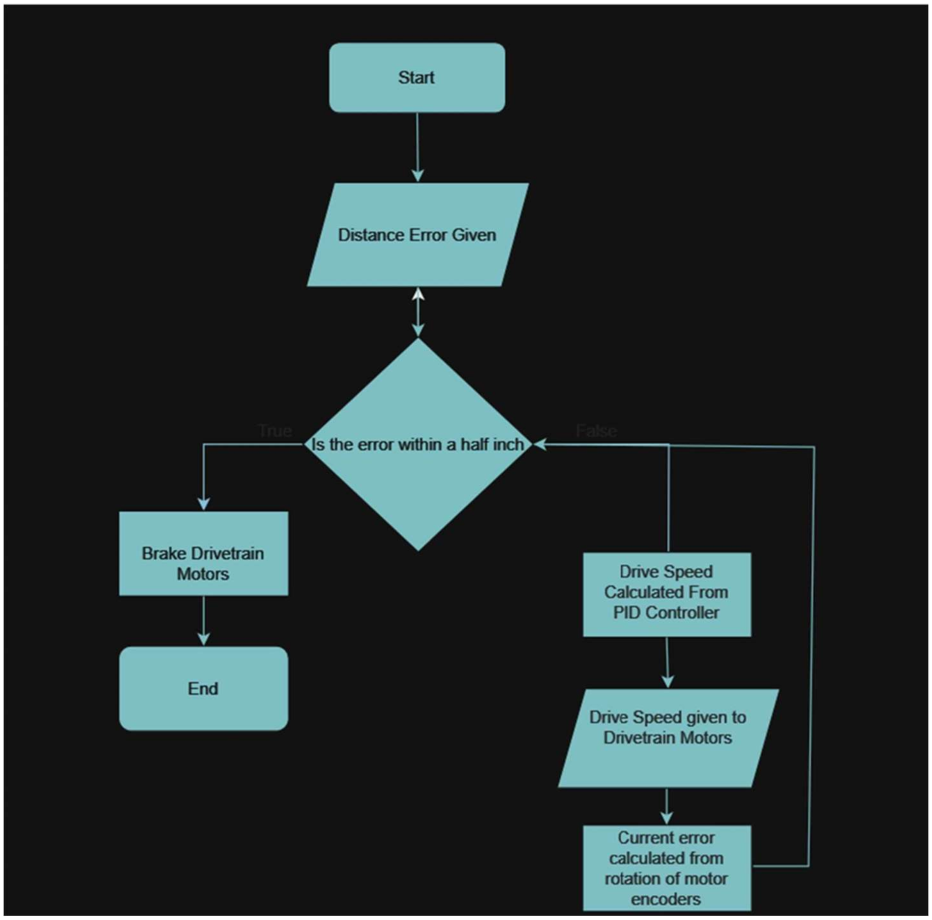

Figure 17: drivePID Flowchart

Heading PID Control Function

The function turnPID was created to control the heading of the robot and allow for point turns to be executed quickly within a small margin of error. The function is called with an input desired heading in degrees. The function checks if the absolute value of the difference in the current heading and the desired heading is greater than half a degree. After this to ensure the most efficient turn is always made the function checks if the error is greater than 180 degrees to subtract 360 degrees or less than -180 degrees to add 360 degrees. Once the error has an absolute value less than or equal to 180 degrees the most efficient turn has been found and the turn can be executed. The error is taken into a PID controller to determine the drive speed with the left drivetrain motors receiving the output and the right drivetrain motors receiving an equal but opposite output to perform a point turn. The inertial sensor is then called to read the current heading and calculate the current error with the loop then repeating until the heading is within half a degree of the desired heading and the drivetrain is stopped.

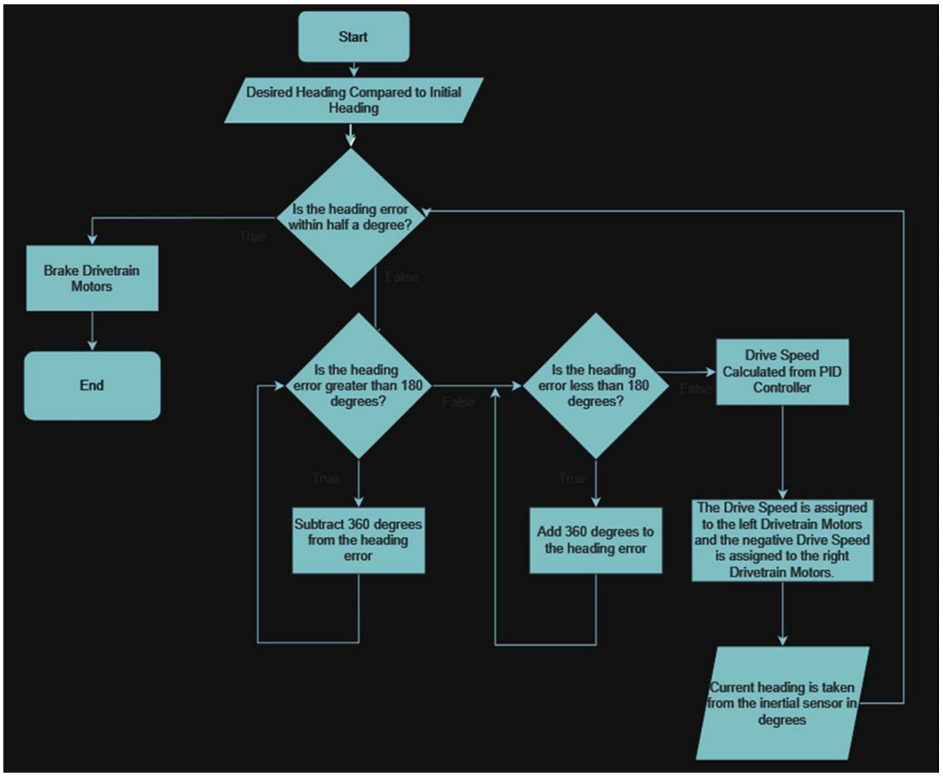

Figure 18: turnPID Flowchart

Sensors

Motor Encoders

The Vex Motors come with their own internal encoders, the importance of defining the gear ratio of the motor cartridge when a motor is initialized relates mostly to the encoders so that the rotational output of the motor can be determined. These encoders have a refresh rate of 50ms allowing for distance calculations to occur 20 times a second

Inertial Sensor

Robot acceleration, direction, and angular velocity may be measured in real time with VEX Inertial Sensors, which improves robot performance throughout competition. These sensors, which come in a lightweight, compact design appropriate for various robotic applications, detect rotational motion. Robots can conduct smooth turns, independently navigate areas, and make well-informed decisions thanks to this real-time data, which also allows for more advanced maneuvers and improved overall performance. By adding inertial sensors to the drivetrain, the robot gains stability and can perform smooth turns, all of which maximize agility and efficiency in competition.

Cost Analysis

Table 6: Cost Analysis Chart

Component	Cost Per Item	Quantity	Total Price
C-Channel 1x2x1x35 (6 pack)	$9.99	2	$19.98
36T Gear V2 (8 pack)	$16.99	1	$16.99
48T Gear V2(8 pack)	$16.99	1	$16.99
60T Gear V2 (8 pack)	$16.99	1	$16.99
72T Gear V2 (6 pack)	$16.99	1	$16.99
84T Gear V2 (4 pack)	$16.99	1	$16.99
Traction Wheels (3.25")	$12.99	2	$25.98
Omni-Directional Wheels (3.25")	$21.99	4	$87.96
Omni-Directional Wheels (4")	$27.29	2	$54.58
VEX Smart Motor	$9.99	10	$99.99
Smart Cables	$11.49	1	$11.49
V5 Controller	$124.99	1	$124.99
V5 Robot Brain	$349.00	1	$349.00
Delrin Plate (2x4x1/4)	$62.80	1	$62.80
Piston (4 Pack)	$86.28	2	$172.56
Air Tank Valve	$8.49	1	$8.49
Reservoir Cartridge/Air Tank	$14.00	3	$42.00
1.50” Standoff (10 Pack)	$9.39	2	$18.48
		Total Cost	$1,163.25

Conclusion

While preparing for the VEXU World Championship, the robot has been designed to be fast, durable, and efficient. The intake is strong, and the wings will be able to use match loads to score more points during the match. The elevation mechanism can also lift both robots into tier E, which is better than any team elevation seen so far in the season.

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