Competitive Design Process for VEX U Competition “Tipping Point”

Misael Marquez, Mechatronics Engineering
Vaughn College of Aeronautics and Technology, NY, USA
misael.marquez@vaughn.edu

Mentor: Dr. Hossein Rahemi and Dr. Shouling He Vaughn College of Aeronautics and Technology, Flushing, NY, USA
hossein.rahemi@vaughn.edu, shouling.he@vaughn.edu

***Abstract* - The following paper outlines the iterative design, build, and programming process for competition robots. The robots will pick up and hold two mobile goals to climb a tipping platform. The robot is also able to collect rings and place them on the branches of the alliance goals. The robot can hold two goals by having one in the mobile goal lift, and another in the pneumatic clamp. The robot scores the goals on the platforms by using the clamp and the four-bar lift. Using the conveyor, the robot can score rings on the alliance goals or can hold them in the conveyor.**

Keywords: Autonomous, Robot, CAD, Robotics, Programming.

I. INTRODUCTION

The challenge released by VEX Robotics for the 2021-2022 season is played on a 12-foot by 12-foot square field. On this field are game elements that may be manipulated by two alliances of two robots. The game elements include 72 purple rings of 4.125-inch diameter. Robots are allowed to score rings onto the bowl-shaped goals to gain points. Two goals belong to each alliance, and three are neutral. These mobile goals can be moved from their originating zone to another, with the two red goals starting in the red zone, two blue goals in the blue zone. The three yellow neutral mobile goals begin in the neutral zone on top double white lines in the center of the field. Each goal is worth 20 points for the respective alliance when it ends in their zone at the end of the autonomous and driver control period. At the end of the match, teams may decide to place a goal on their respective colored platforms to change the goal’s worth from 20 to 40 points, or to place a robot on the platforms for an additional 30 points. Rings may also be placed on the goals for an additional one point if scored in the bowl. Three points are awarded if a team scores a ring on the branches of the alliance goals or low branches of the neutral goals. Ten points are awarded to a team that can place a ring on the top branches of the neutral goal. Rings on the neutral goals only count if they end up in an alliance zone. The layout of the field for the tournament competition is shown in Fig.1.

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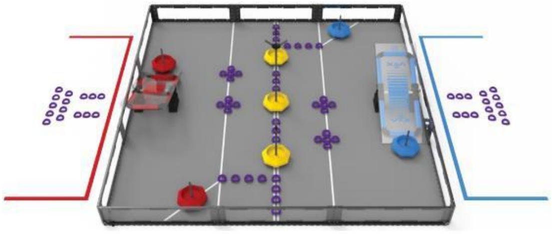


Fig. 1: Tipping Point Tournament Field Layout [1]

A. *Objective*

The objective of this project is to construct and program a robot that can move around the competition field while collecting and placing mobile goals. While moving around the field, the robot should also be able to collect rings and deposit them onto the mobile goals.

B. *Related Background*

Drivetrain: a robot subsystem that controls the movements of the robot on the field. This consists of a frame or base that the rest of the robot builds onto. The drivetrain also takes the most amount of damage from opposing teams and must be strong enough to deal with the hits and the robot’s weight.

Lift: A lift is a robot subsystem that raises other subsystems or game elements to the desired height.

Conveyor: The conveyor is a subsystem that controls the movement of rings in the robot. The conveyor moves the rings from the ground to the tip of the branch on an alliance mobile goal. On one side of the conveyor is a polycarbonate plate that compresses rings onto the belt, thus allowing the ring to follow the conveyor.

II. ENGINEERING REQUIREMENTS

Compact - The robot must fit within the 15-inch cubed size constraints [2]. After the match starts, the robot may expand to any desired height but has a maximum expansion limit of 36 inches, point to point.

Simple - The robot must be simple to reduce the number of working parts and make maintenance easier. Simplicity also reduces the chances of a serious failure in a design.

Robust - The robot must be able to take any hits or pins delt by the opposing team. The robot must also be able to handle any forces applied to it if it accidentally falls off the platform when climbing.

III. ITERATIONS OF DESIGN

Different designs were prototyped and tested before use in competition. All concepts listed and described below all manipulate the rings and mobile goals.

A. First Concept

The first concept consisted of a drivetrain, a cascade lift, a chain bar lift, a conveyor belt, funneling wheels, a four-bar mobile goal lift, and a cup. The drivetrain included six motors that were fed into a gearbox that transmitted the power to four Omni-wheels via chains and sprockets. The gear ratio from the motors to the wheels was 1:1. The cascade lift, chain bar lift, conveyor belt, and funnel wheels each had only one motor. The mobile goal lift had two motors. The concept idea was that when the cascade lift and chair bar were collapsed, the conveyor could intake rings from the field and onto the cup that is attached to the end of the chain bar. From here, the cascade lift and chain bar could lift the cup to the neutral goal branches and score rings. The funneling wheels move rings from the front of the driving wheels to the middle of the robot, feeding the conveyor. If the lifts were not collapsed, the mobile goal lift could move a mobile goal into place and have the rings score on there instead. Fig. 2 shows a simple design that was created on SolidWorks to find the best location for motors and mounts.

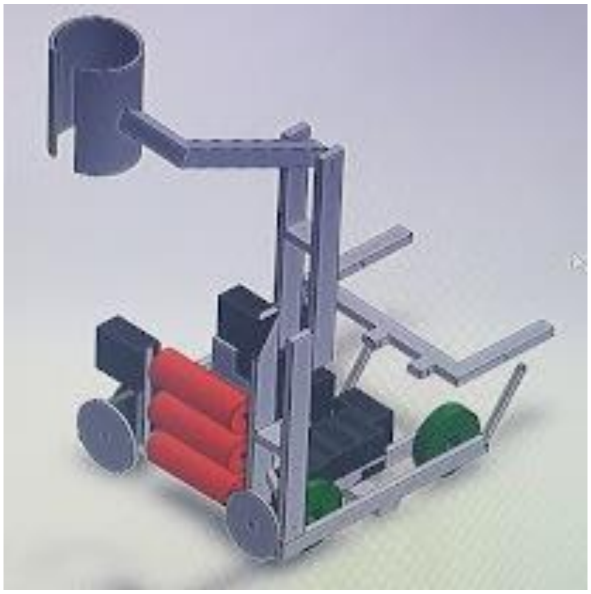


Fig. 2: First Iteration Simple Design

Following the simple design, a more completed design (Figure 3) was constructed using aluminum c-channels and custom parts. The design proved to be too complicated with the several different subsystems in a very small space. It was deemed the process could be completed with less complexity.

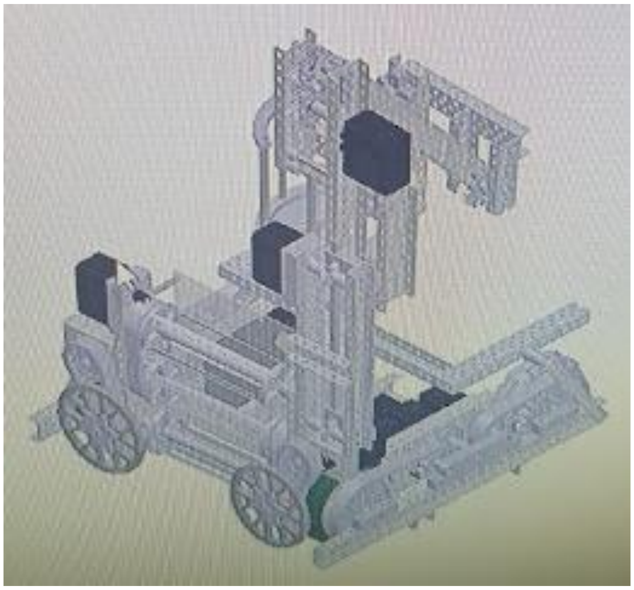


Fig. 3: First Iteration Design with C-Channels.

B. Second Concept

The second design consisted of a six-motor drivetrain, one motor conveyor, one motor mobile goal lift, and two motor four-bar lifts. The idea behind this design is that the conveyor is mounted onto the end of the four-bar lift. While the robot moves on the field, the conveyor can be lowered to ground height to collect rings. When an alliance goal is in the mobile goal lift, rings can deposit onto the alliance goal's branch via the conveyor belt system. Using the four-bar lift, the conveyor can score rings onto the neutral goal's branches.

The drivetrain consisted of six 200 rotation per minute VEX V5 motors that are then fed into a gearbox [3]. This gearbox then transmits the power in the gearbox to the drivetrain wheels with a gear ratio of 1:1. The mobile goal lift used a non-parallel four-bar mechanism to lift the mobile goal to where its branch is tilted towards the conveyor belt. A 100 rotation per minute motor drives the lift with a gear ratio of 1:3. On the lift are three linkages, one driving and two supporting. Connecting the three linkages is a C-shaped plate that holds the bottom of the mobile goal. The two supporting linkages keep the lift steady as the mobile goal is transitioning from being on the ground to being on the robot. A crossbar on top of the lift prevents the mobile goal from tipping off the robot once the goal has been collected.

The conveyor belt system consisted of a chain loop with flap attachments on some of the chain linkages. The chain was directly driven by one 200 rotation per minute motor. Behind the chain, the loop was a polycarbonate sheet that applied pressure to the rings when collected. This allows the rings to follow the conveyor until the rings reach the mobile goal branch.

Fig. 4: Implementation of the Second Iteration Design

The conveyor system would misplace rings on the mobile goal branches. Standoffs were placed right before the conveyor releases the ring to further control the ring's movement. The standoff acts as a funnel that centers the ring along the conveyor where the flaps on the conveyor would touch along a point centered on the ring.

Another solution for the missing rings is the use of two parallel conveyor systems. This concept uses the ring's behavior to score them on the mobile goal branches. The rings follow the conveyor around the end of a sprocket. If using two sprockets that are spinning in opposite directions, their effects would negate each other thus allowing the rings to release more centered on the branches. This would depend on the speed of the sprockets, and they must be the same. If one is spinning quicker, the ring would follow that sprocket instead.

The standoff idea was the best and was replaced by plates on the side and a finger at the top. The side plates keep the rings centered along the mobile goal branches. The finger at the top controls the departing angle of the rings from the conveyor and the angle of approach of the rings from the conveyor. The finger also controls how far back the rings are launched.

Along the intaking area of the conveyor were two intaking wheels that were parallel to one another. These gave the conveyor a greater room for error when collecting rings on the ground. In between the two wheels is a flexible panel that provided enough compression on the ring such that they may not escape whilst the conveyor is attempting to move it up. Previously the ring would get stuck at the beginning of the front panel.

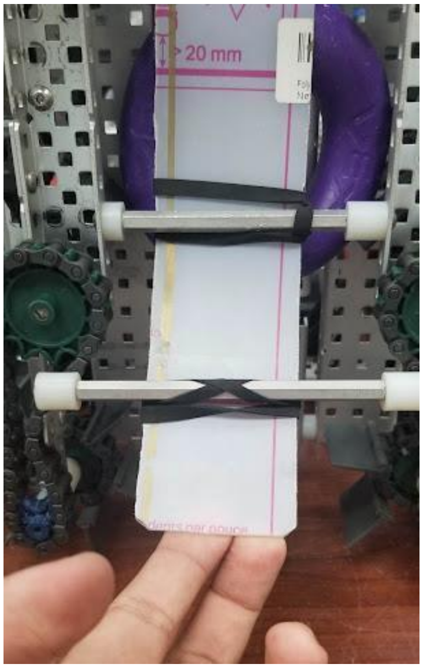


Fig. 5: Two parallel intaking wheels with the flexible panel

The conveyor was rebuilt to use flaps as the main conveyor going down the center and three-inch vex pro flex wheels on the sides to aid in the collection of rings. A funnel behind the vex pro wheels was added to the conveyor to center the rings after the collection occurred. This was simpler and more efficient than the two parallel conveyors and wheels. Future designs used this system.

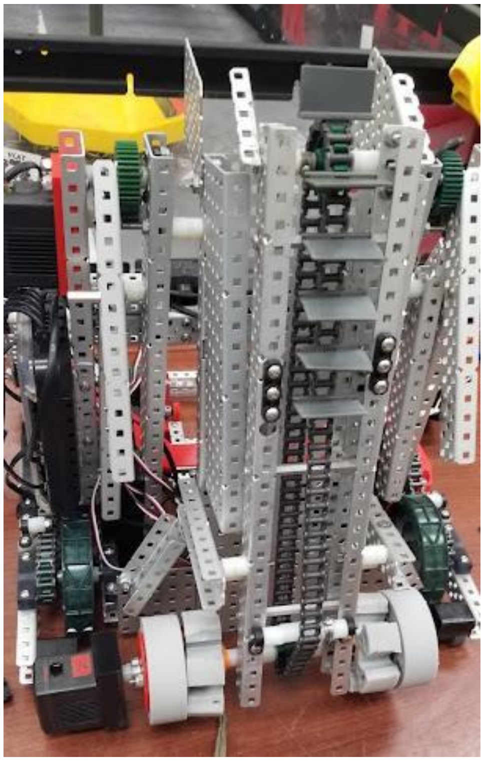


Fig. 6: Rebuilt Conveyor Belt System

C. Third Concept

The second design was too simple to function correctly thus introducing the third iteration. This iteration consists of a drivetrain, a mobile goal lift, a double reverse four-bar lift, a conveyor, and a goal spinner. The concept is to place rings onto the alliance mobile goals when the double reverse four-bar is collapsed. The robot could hold a few rings in the conveyor and raise its double reverse four-bar lift to place rings onto the neutral branches. The goal spinner would align the branches with the conveyor belt in preparation for depositing rings.

The conveyor is similar in construction to the third concept but is smaller and lighter such that the lift on the double reverse four bar can raise it easily. The conveyor uses one 200 rotation per minute motor that drives a sprocket and a chain loop around it. The drivetrain consisted of six 200 rotations per minute motors connected via a similar gear and sprocket layout as the first and second iterations. The mobile goal lift consisted of a two-bar mechanism and has a wheel to rotate the mobile goal about its center such that the robot may score rings on the low or high neutral branches. This is important as the branches are perpendicular to each other. The robot's conveyor lift uses a double reverse four-bar to raise the conveyor to the desired height with the highest reaching the tall branch on the neutral goal. The mobile goal lift is powered by one 100 rotation per minute motor with a gear ratio of 1:5. The goal spinner consists of a motor that spins at a rate of 200 rotations per minute. On the motor is a three-inch vex pro flex wheel that contacts the top of the mobile goal's base.

The lift was rebuilt several times to accommodate the spinner. This is due to the mobile goal not making enough contact with the goal spinner. Ideas of having the goals rest on the wheels alone were introduced but did not function well due to the lift's instability vs friction ratio. When increasing stability, the friction is increased, and when the stability is decreased, the friction decreased. There was not a perfect balance between the two.

D. Fourth Concept

The third design was far too complex and difficult to perfect. The design was reduced to a conveyor, mobile goal lift, and drivetrain as a base layout for the fourth iteration. This iteration was repeated twice to create two slightly different designs. One would have a branch such that rings may be scored on the lower neutral branches. This was deemed a priority by the team as the teams playing the matches would have one or two neutral goals in their zones end of a competitive match. Ring play from the branch of the robot onto the branch of the neutral goals could provide an extra boost in points at the end of a match. The other would have a four-bar lift with a clamp in the front. This was also deemed a priority by the team to compliment the first design to double the worth of goals at the end of matches.

The branch robot would include a branch and a chain bar. The chain bar was used to allow the branch to change its angle. The branch would require one angle to introduce rings onto it (Fig.7), and one to expel rings onto a neutral goal branch (Fig.8). The branch is fed by the robot's conveyor by taking up the space a mobile goal would take up if it were also fed by the conveyor.

Fig. 7: Branch Robot Design Collapsed

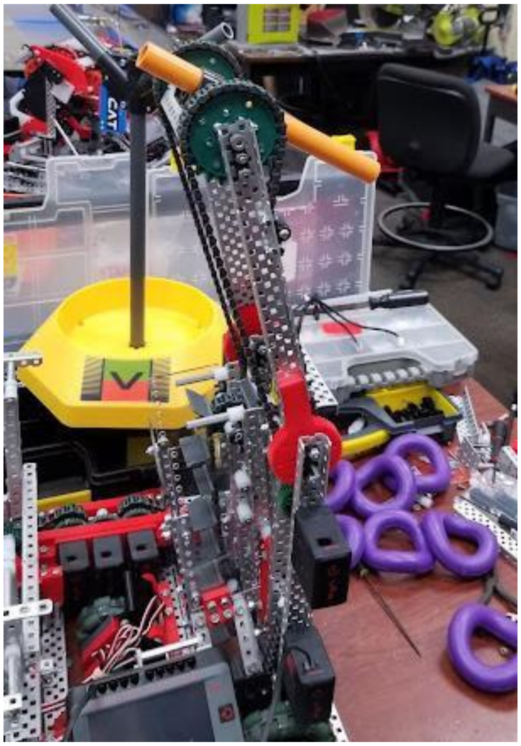


Fig. 8: Branch Robot Design Extended

The clamp design first started as a forklift design. The forks were selected for their simplicity and independence from an actuator. The four-bar lift was selected for its size when compared to other lifts such as a double reverse four-bar or a scissor lift. The four-bar was constructed with the forks on its end. The forks can rotate upwards to comply with the 15-inch size constraint (Fig. 9) and drop down at the start of the match (Fig. 10).

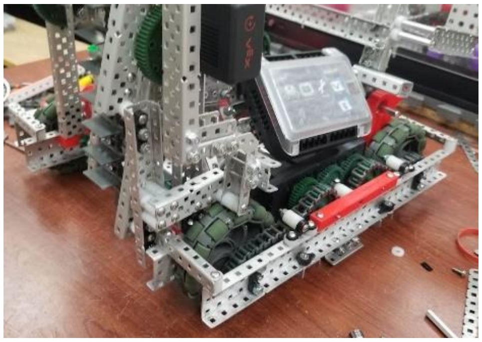


Fig. 9: Forks Collapsed

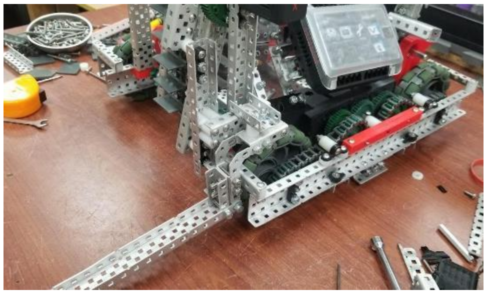


Fig. 10: Forks Expanded

The forks were replaced by a pneumatically actuated clamp as the forks could cause the design to fit outside of the 36-inch horizontal expansion limit. The lift also requires a great deal of support to prevent instability. This sort of support would be hard to achieve. The forks also collapsed under the weight of the mobile goal. The clamp was constructed using a double-acting pneumatic piston with a two-hole c-channel at the bottom to serve as a lip where the goal may rest upon. Standoffs attached the bottom two-hole c-channel to the rest of the assembly that contained the moving arm. The finger was designed to start upright on the robot to fit within the 15-inch size restraints (Fig.11), while also being able to fold into the goal's bowl (Fig. 12). The clamp is also designed to be as thin as possible to fit in front of the pre-existing conveyor.

Fig. 11: Clamp Released

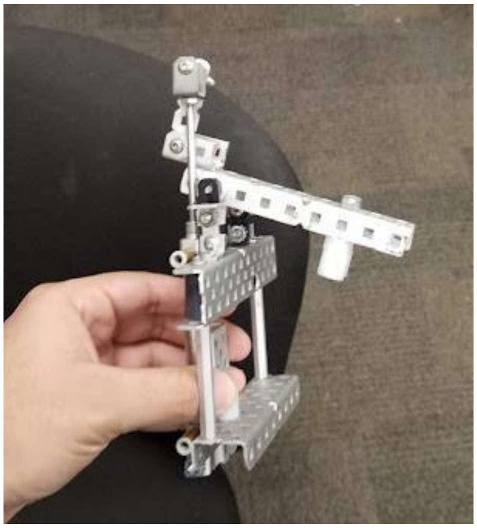


Fig. 12: Clamp Extended

The fingers and lip were 3D printed to reduce the number of parts on the clamp and to better accommodate the goals (Fig. 13). The lip can fold up and into the robot to start the match, then folds down once the match has started by using a half-cut c-channel as a physical stop to prevent it from falling too far. On the ends of the fingers are rubber bumpers that grip the inside of the bowl to keep the goals in place.

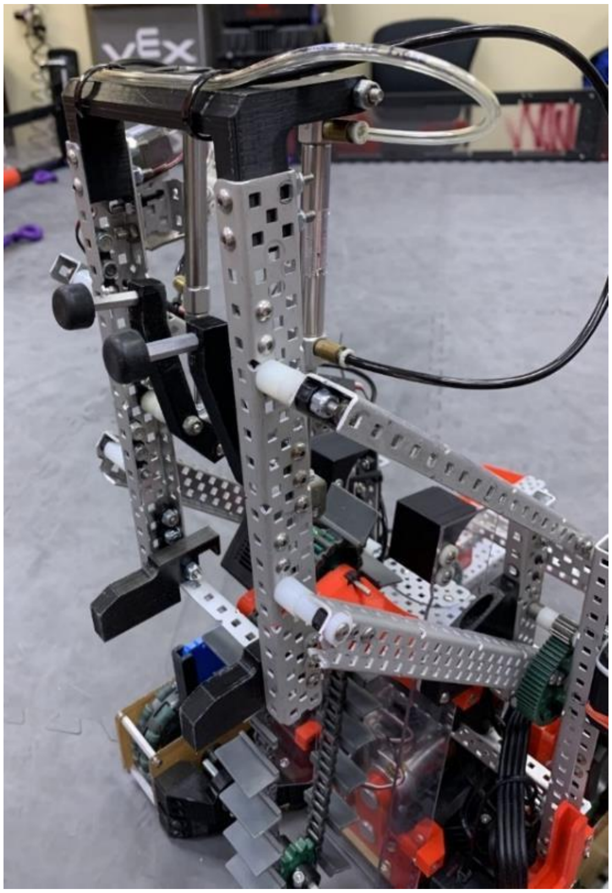


Fig. 13: 3D Printed Clamp

E. Fifth Concept

The previous two robots underwent several matches against local high school teams. The matches were successful but showed that the fourth iteration robots were not competitive enough. The robot with the clamp and four-bar was redesigned as it showed the most promise. Two of these were built to match the gameplay of high-level games. On the other hand, ring play could be very important in the VEXU game rather than the VRC game. The VRC game's autonomous period is only 15 seconds which just barely gives enough time for a team to grab the goals that they would like and score rings on them. This along with the rules stated in the tipping point rule book only gives the team 15 seconds of the protective zone where a team could score rings. The VEXU autonomous period is 45 seconds long. This gives VEXU teams more time to accomplish what they would like to do in the autonomous period. One thing that the teams may want to accomplish is to score rings onto their mobile goals. In the last thirty seconds of a match, a team is not allowed to touch the opposing team's platform, or they will face a penalty. For this, teams stay in their zone. High school teams would only have 45 seconds where they are protected in their zones, whereas the collegiate teams have a minute and 15 seconds, thus making ring play extremely valuable towards the end of a match. Two clamp designs are constructed, while also keeping the branch design in mind for future iterations.

A simple assembly was constructed to determine how the robot's different subsystems will be laid out (Fig. 14). From the design, the clamp seemed to be the hardest to perfect. The conveyor, four-bar lift, clamps, and drivetrain were assembled. The conveyor and clamp are the two subsystems closely monitored due to their close locations.

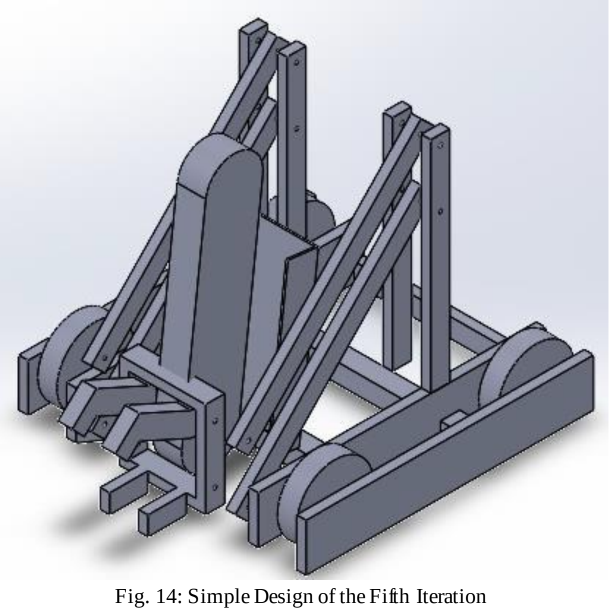


Fig. 14: Simple Design of the Fifth Iteration

The robot's conveyor system was the first to be created. The conveyor system was to remain the same from the previous iteration since it was functional. An approximation of where the driving and driven sprockets were transformed into a SolidWorks sketch. From here, the rest of the design could be built.

The clamp was rebuilt to fit within 15 inches again (Fig. 15). The clamp will contain two double-action pistons to resolve the pressure created by the fingers and allow space for the conveyor to exist on the robot. The clamp frame had gone through some minimization. Seen as there will be more space next to the conveyor, the pistons for the clamps may be mounted further back on the robot.

Fig. 15: Prototype of Fifth Iteration Clamp

The drivetrain, conveyor, and mobile goal lift were initially constructed as they are not moving to a different point on the robot. The conveyor consisted of two sprockets floating in mid-air to remove any constraints when thinking of how to create the conveyor. The drivetrain is constructed out of plates to simplify the design in general and to make maintenance easier.

Prototypes of chain linkages belts were created to see if they require a tensioner. One was created for the drivetrain Fig.16, and the other was created for the conveyor system. Fortunately, none were required. Figure 17 shows the final design that was completed after every subsystem had been prototyped and enough information was available.

Fig. 16: Drivetrain Chain Tension Test

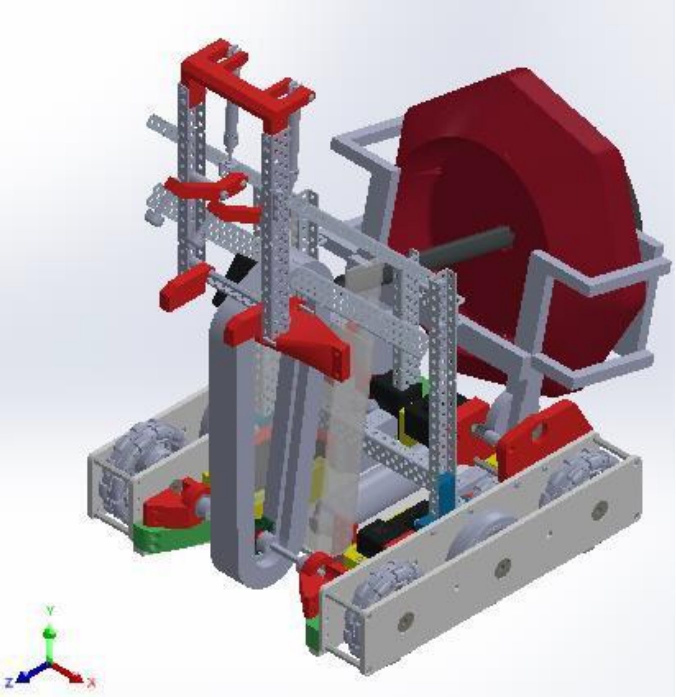


Fig. 17: Completed CAD Assembly for the Fifth Design

The robot was constructed out of acrylic. This was done by using a laser cutter. Acrylic is a much cheaper material but illegal to use for competition. However, this will make a great substitute to test and find mistakes in the CAD concept. These eventually were replaced for the durable and legal Delrin. Ball bearings are used on the drivetrain to help reduce friction on the drive train and to allow a high-strength shaft to be used for the wheels. Moreover, the design allowed the motors to be removed from the assembly by removing a block. This block applies pressure onto the motor that keeps it in the assembly. Other items such as sensors and air reservoirs are also mounted via the bottom of the drivetrain. Screws in Figure 18. may be removed and the desired item comes out. The heavier items on the robot were moved as low as possible to keep the design stable when moving the heavy mobile goals above the platform.

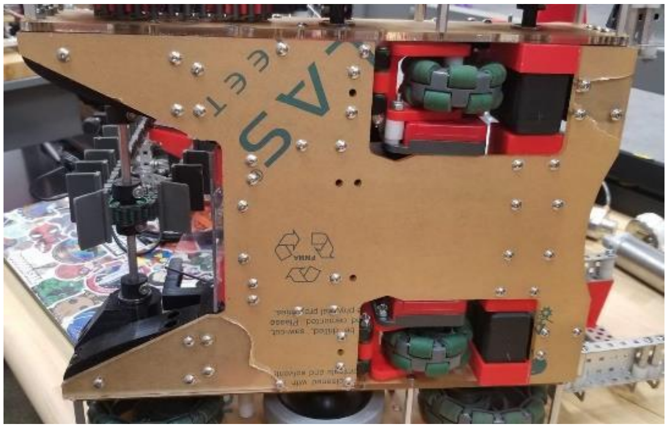


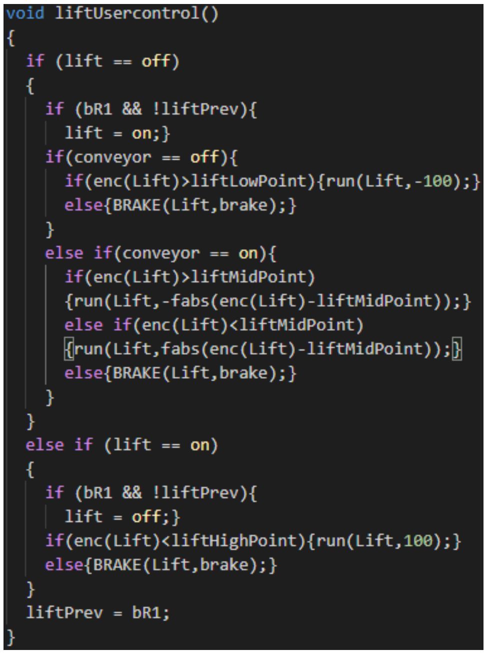
Fig. 18: Underside of the robot drive train.

IV. SOFTWARE

A program was created in C++ to control the robot's functionalities. The program is split into user control functions, move to position functions, and scripts. These were created using VEX Code Pro V5 software [4]. This software was created by VEX Robotics to work alongside their electronics.

A. *Automation:*

Some automation was done to lessen the skill load on the robot's operators. Automation includes controlling the height of the four-bar lift and controlling the height of the mobile goal lift. One of the more important aspects of automation is changing the height of the four-bar lift when the conveyor is running. For instance, if the four-bar lift was at its lowest height, and the conveyor was enabled, the four-bar's lowest height is now slightly higher up. This allows for rings to slide under the four-bar lift and into the conveyor. An example of such a control system is included. Using the concept of a proportional controller, the program adjusts the motor's spin rate based on its error, or by how far away the measured value is from the target value [5]. This was measured using the built-in motor encoders.

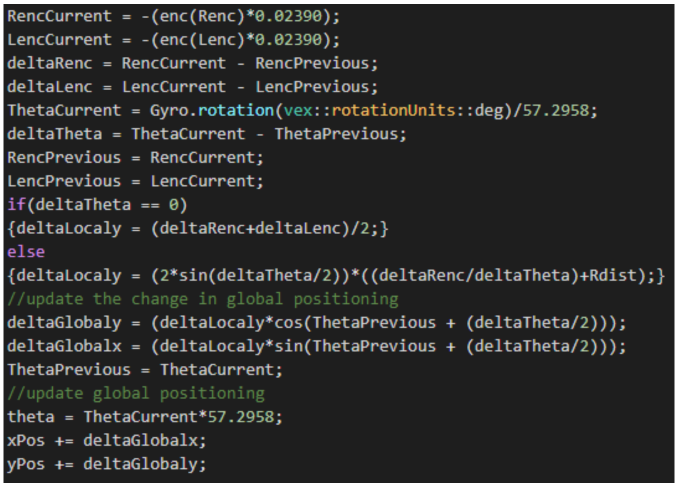


```
void liftUsercontrol()
{
  if (lift == off)
  {
    if (bR1 && !liftPrev){
      lift = on;}
    if(conveyor == off){
      if(enc(Lift)>liftLowPoint){run(Lift,-100);}
      else{BRAKE(Lift,brake);}
    }
    else if(conveyor == on){
      if(enc(Lift)>liftMidPoint)
      {run(Lift,-fabs(enc(Lift)-liftMidPoint));}
      else if(enc(Lift)<liftMidPoint)
      {run(Lift,fabs(enc(Lift)-liftMidPoint));}
      else{BRAKE(Lift,brake);}
    }
  }
  else if (lift == on)
  {
    if (bR1 && !liftPrev){
      lift = off;}
    if(enc(Lift)<liftHighPoint){run(Lift,100);}
    else{BRAKE(Lift,brake);}
  }
  liftPrev = bR1;
}
```

Fig. 19: Function that runs the driver control automation

B. *Localization*

Included on the drivetrain are dead wheels that act as the robot’s localization system that is relative to its starting point. This is far superior to dead reckoning as if there are any mistakes in dead reckoning, it doesn’t correct itself as it believes its previous location is correct. Using the dead wheels, the current encoder values are read by the program and are converted into a change in distance in inches. The program then compares the previous and current values to detect a change location. From here, the program determines whether they are the same value to which the robot understands it moved perfectly forward or backward. If not, the program will implement some trigonometric calculations to compute its change in position. Its location is constantly being updated independent of the drivetrain’s functionality. Reference [6] describes the algorithm used and its proof in greater detail.



```
RencCurrent = -(enc(Renc)*0.02390);
LencCurrent = -(enc(Lenc)*0.02390);
deltaRenc = RencCurrent - RencPrevious;
deltaLenc = LencCurrent - LencPrevious;
ThetaCurrent = Gyro.rotation(vex::rotationUnits::deg)/57.2958;
deltaTheta = ThetaCurrent - ThetaPrevious;
RencPrevious = RencCurrent;
LencPrevious = LencCurrent;
if(deltaTheta == 0)
{deltaLocaly = (deltaRenc+deltaLenc)/2;}
else
{deltaLocaly = (2*sin(deltaTheta/2))*((deltaRenc/deltaTheta)+Rdist);}
//update the change in global positioning
deltaGlobaly = (deltaLocaly*cos(ThetaPrevious + (deltaTheta/2)));
deltaGlobalx = (deltaLocaly*sin(ThetaPrevious + (deltaTheta/2)));
ThetaPrevious = ThetaCurrent;
//update global positioning
theta = ThetaCurrent*57.2958;
xPos += deltaGlobalx;
yPos += deltaGlobaly;
```

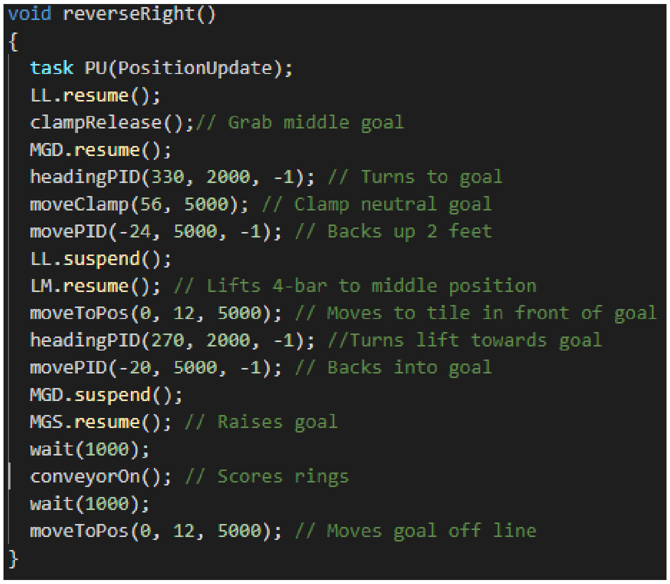
Fig. 20: Localization algorithm using dead wheels

C. *Skills*

The skills competition is a challenge where a team is given one minute with a modified tournament field layout to score as many points as possible [7]. The skills ranking is important to have as high as possible to win the excellence award which qualifies for the world championship. This challenge also includes a programming and driver-controlled section. Using the above algorithms and functions, a script was created to control the robot during the one-minute challenge.

D. *Tournament*

The tournament competition includes an autonomous period where a team is given 45 seconds on a tournament field layout to score as many points as they would like. This occurs with another team on the field. The autonomous period is a time when a team can get possession of as many neutral goals as possible. Without possession, the team would be at a great disadvantage. An example of a competition script is shown in figure 21.



```
void reverseRight()
{
  task PU(PositionUpdate);
  LL.resume();
  clampRelease();// Grab middle goal
  MGD.resume();
  headingPID(330, 2000, -1); // Turns to goal
  moveClamp(56, 5000); // Clamp neutral goal
  movePID(-24, 5000, -1); // Backs up 2 feet
  LL.suspend();
  LM.resume(); // Lifts 4-bar to middle position
  moveToPos(0, 12, 5000); // Moves to tile in front of goal
  headingPID(270, 2000, -1); //Turns lift towards goal
  movePID(-20, 5000, -1); // Backs into goal
  MGD.suspend();
  MGS.resume(); // Raises goal
  wait(1000);
  conveyorOn(); // Scores rings
  wait(1000);
  moveToPos(0, 12, 5000); // Moves goal off line
}
```

Fig. 21: C++ Script Controlling the Robot’s Autonomous Movements

V. CONCLUSION

The robots are exact copies of one another. These have the same functionality which helps make progress much quicker than two separate designs. The two robots have the same six 200 rotation per minute motor drivetrain, two 100 rotation per minute four-bar lifts, one 100 rotation per minute mobile goal lift, and one motor conveyor. The tuning required to automate the robots was also much quicker to achieve as the programs run the same program with no modifications. The designs are very robust, lasting several competitions without any serious failures. When failure did occur, the part was replaced within minutes before a very important finals match.

VI. RESULTS

After three competitions, the team underwent a record of 2-3 at the first tournament, ultimately leaving the team ranked 4th out of 6 teams. However, the team ranked first in the skills competition with a score of 417. At the second competition, the team underwent a record of 7-3, ranking the team first out of eight teams. The team ranked first in skills with a score of 496. At the third competition, the team had a record of 8-0 and first place in the skills competition with a score of 556. The team achieved tournament champion in the last competition and tournament finalist in the second. The team also achieved the excellence award at all three events and is qualified for the world championship.

Fig. 22: Team VCAT Post Third Competition

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