Smart Autonomous Robot Design for VEX U Challenge “In The Zone”

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Abstract- This project outlines the design, construction, and programming of a robot that can pick up and stack objects accurately. The objects are 17.78 cm cones weighing 0.12 kg., and 24.38 cm mobile goals weighing 1.68 kg, that are pre-placed inside a 12’x12’ perimeter. The robot can locate the mobile goals autonomously with the use of timers and stack the cones on top of these mobile goals using an infrared sensor. A cone stacking mechanism will be constructed to create the highest stack of cones reaching over one meter off the ground. The mobile goal mechanism is designed to lift over 2.72 kg. The cone stacking mechanism will use a combination of four motors along with rubber bands. The addition of rubber bands increases the rate at which the lift expands and contracts. To efficiently pick up the cones at a fast rate a 3d-printed claw was designed to attach to the lifting mechanism. This report will outline the process of selecting the cone stacking mechanism, the claw, the mobile goal mechanism, and the autonomous capabilities of the robot.

Keywords: Robotics, CAD, Design, Automation

I. INTRODUCTION

Every April, VEX Robotics releases a challenge that pushes the boundaries of engineering through robotics. This year the challenge is called ‘In the Zone [1].’ The challenge is played on a 12’x12’ field where two teams, red and blue, design, build and program robots to compete head to head in matches. These matches consist of a forty-five second autonomous period that is then followed by one minute and fifteen seconds of driver control. In this challenge, there are fifty-two (52) cones available as scoring objects on the field. There are also thirteen pre-loaded objects that are available to each team throughout the match. Each team begins with their robot placed inside the five-point zone and must be touching the ten-point zone pole. Each team has three scoring zones along with a stationary goal. The zones include a “20-point zone,” “10-point zone,” and “5-point zone.” Teams also earn bonus points for having the highest stack in each zone and on the stationary goal and parking the robot at the end of the match. A bonus is also given to the team that finishes with the most points at the end of the autonomous period.

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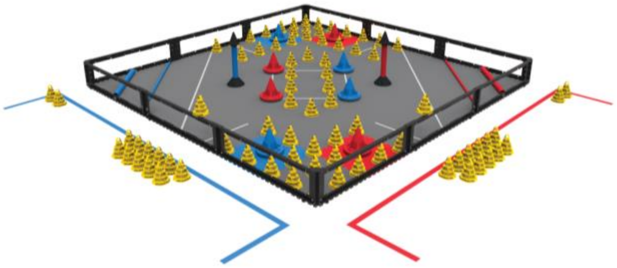


Figure 1. In The Zone, Field Set Up

A. Objective

The object of this project is to design, build, and program a robot that can efficiently lift mobile goals and can rapidly and efficiently stack cones and place the mobile goal into the scoring zones. To accomplish these goals first, it is necessary to create a mobile goal lifting mechanism that can handle the necessary weight of 2.72 kg. To achieve the second goal, it is necessary to create a cone stacking mechanism that is fast and can expand to a height of upwards of one meter.

B. Related Background

Mobile Goal Lift: The mechanism that lifts the mobile goals could be powered by either DC motors or pneumatics. Since the mobile goals will be lifted multiple times throughout the match, DC motors were the more resourceful power source to actuate the mobile goal lift. When using pneumatics to actuate the lift, it was found that the mechanism was unable to accurately grab the mobile goal and hold the mobile goal with cones stacked on top of it multiple times.

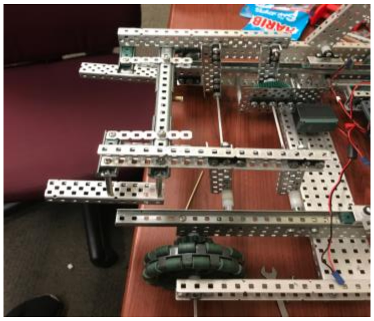


Figure 2: Pneumatic Mobile Goal Lift

Another issue with the mobile goal lifting mechanism was that there was only one DC motor available to power this mechanism. Following VEX guidelines only twelve motors are allowed per robot. Once the motors were all distributed to the other components of the robot, only one was left for the mobile goal lifting mechanism.

Cone Stacking Mechanism: Two concepts were found to be effective for this seasons challenge. These mechanisms include the scissor and the double reverse four bar.

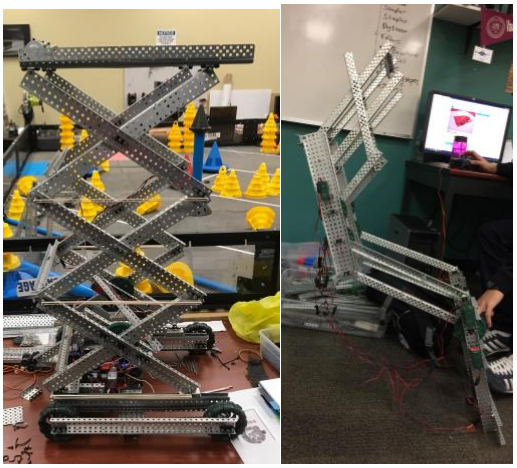


Figure 3: Scissor Mechanism and Double Reverse Four Bar Mechanism respectively

II. ENGINEERING REQUIREMENTS

Creating a successful robot in VEX Robotics' "In the Zone" 2017-2018 season the robot needs to have the following characteristics:

Agility - The robot must have a powerful drivetrain which propels it around the field as fast as possible. The machine itself needs to be light enough to go over the 10-point pole located at opposing corners of the field to score a mobile goal in the 20-point far zone.
Dependability - Construction of the robot must be sturdy enough to withstand contact forces sustained by the opposing team during the duration of the match. Furthermore, the robot needs to be durable to withstand collisions with game elements, the parameter, and even the stationary goals located in the center of the field.
Functionality - The robot must be designed in a way that it can productively pick up mobile goals and stack cones on top of them, promptly. The robot also must place the cones and mobile goal in the 20-point zone and 10-point zone located on the field without tipping the stack or the robot.
Simplicity - The robot must be programmed in a way that relieves the driver of many of the controls by pressing a single button via the remote control which completes multiple functions. This allows the driver to plan the robots next move strategically without a loss of time.

III. HARDWARE DESIGN

A. Mobile Goal Lift

When deciding how to design the mobile goal lift it was noted that it had to be wider than the mobile goal itself. The mobile goal has a diameter of 25.40 cm. The design that was implemented was a four bar lift as shown in Figure 4.

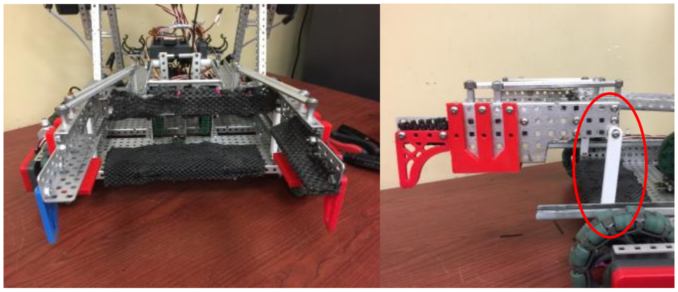


Figure 4. Mobile goal lift front and side view, respectively

A.1 Four Bar Mechanism

The lift mechanism is a four-bar lift that is tall enough to lift the mobile goal over the 20-point zone pole. The 20-point pole is 6.05 cm in diameter meaning that the four-bar needs to lift over 8.53 cm to account for the bottom of the mobile goal that extends past the base of the mobile goal lift. The mobile goal is powered by a low-speed motor with a 1:5 gear ratio. The addition of the gear ratio produces more torque which allows the mobile goal lift to pick up the mobile goal with multiple cones on top of it. With the addition of torque comes with a loss of speed.

Gear Reduction = Driven Gear Teeth / Driving Gear Teeth = 60 / 12 = 5 (1)
Output Torque = (1.67 N-m) (5) = 8.35 N-m (2)
Output Speed = Input Speed / Gear Reduction = 100 RPM / 5 = 20 RPM (3)

A.2 3D Parts

The most efficient way to pick up the mobile goals is by grabbing them from the side edges. The mobile goals given in the challenge have a 2.24-cm edge. This edge allows a C-channel to rest underneath and grab the mobile goal. The robot has C-channels that are thirteen holes long and are what properly hold both sides of the mobile goal during the lift. 3d parts were created in SOLIDWORKS 2016 to reinforce the portion of the C-channel that goes under that edge of the mobile goal. This 3d part created is known as the mobile goal grabber.

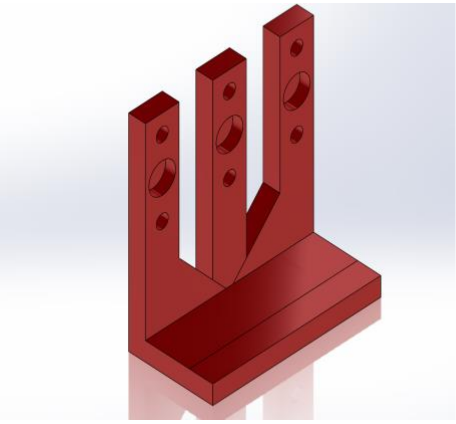


Figure 5. Mobile Goal Grabber CAD Model

Also, to keep the mobile goal lift at the correct height off the ground, the mobile goal footer was created and attached to the end of the C-channels. The footer and grabber pieces combined to allow for the mobile goal mechanism to easily slide the mobile goal into the 20-point zone without knocking the cones off the mobile goal. The CAD models of the mobile goal grabber and footer can be seen in Figures 5 and 6.

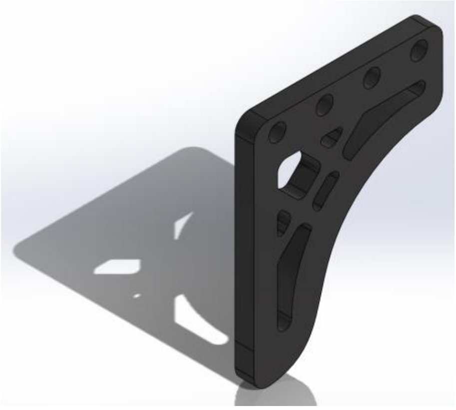


Figure 6. Mobile Goal Footer CAD

To create a rigid four-bar design for the mobile goal lift, the front part of the four-bar was also 3d printed. This part can be seen in Figure 4 as the white object in the image. The reason this part was printed instead of being made of metal was due to the available spacing in the cut out of the drivetrain. To create this part, the measurements were found by setting up the back bars of the lift and then accurately measuring the height of the front bars.

B. Scissor Lift

When choosing a lift that was most efficient for stacking cones, it was known that the mechanism would need to be lightweight and fast. It was decided that a simple scissor lift design would be the best option for this challenge.

B.1 Iteration One

For the first prototype of the scissor lift, a two-stage lift was created. Each stage of the lift can be distinguished by the ‘X’ shape created by the intersecting C-channels. The two-stage Scissor Lift was made with 8 '35-hole (17.5”) x 3-hole (1.5”)' C-channels, four C-channels on each side. To connect the C-Channels, a screw with a nylon nut was used. This allowed the scissor lift to be fastened together tightly without having excess friction at each joint since the screws are still able to rotate. Additionally, to further decrease friction, each C-channel joined together was slightly separated using 0.635 cm nylon spacer. By implementing nylon spacers, allowed for the scissor lift to actuate in a linear motion without opposing C-Channeling scraping against each other creating friction.

Once both sides of the scissor lift were constructed, the C-channels were connected to the drivetrain using linear slides. Plastic internal slides were attached to the ends of the C-channels, which once the scissor lift was actuated; would slide through the external metal slides mounted to the drivetrain. A similar setup was used at the top of the lift to improve stability.

Figure 7. Iteration One of the Scissor Lift

B.2 Lift Power

To power the scissor lift through its vertical linear motion, four VEX 2-Wire Motor 393 (two on each side) are driving an 84-tooth gear with the use of a 12-tooth gear mounted directly to the motor. The two gears together create a 1:7 gear ratio (4), which provided more torque for extending the scissor lift. Two motors spinning in opposing directions driving the 84-tooth gear produced 14.56 N-m of torque (5) while allowing the large gear to rotate at a free speed of 22.85 RPM (6).

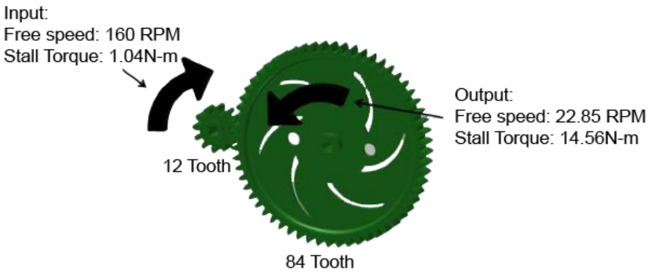


Figure 8. 1:7 Gear Ratio

Gear Reduction = Driven Gear Teeth / Driving Gear Teeth = 84 / 12 = 7 (4)
Output Torque = (2) (1.04 N-m) (7) = 14.56 N-m (5)
Output Speed = Input Speed / Gear Reduction = 160 RPM / 7 = 22.85 RPM (6)

B.3 Iteration Two

Once the first prototype was completed, it was evident that there were a few issues with the design that needed to be corrected. The extra height provided by the drivetrain being attached to the scissor lift was still inadequate to achieve a high stack. To fix this an additional 'X" stage consisting of four 35-hole (17.5") x 3-hole (1.5")' C-channels was added to the top of the scissor lift. The addition of the "X" stage significantly increased the maximum achievable height and the number of cones that could be stacked. Another issue that arose was the instability of the lift as it would sway when it was fully extended. To fix this structural issue, support was added at each stage of the robot.

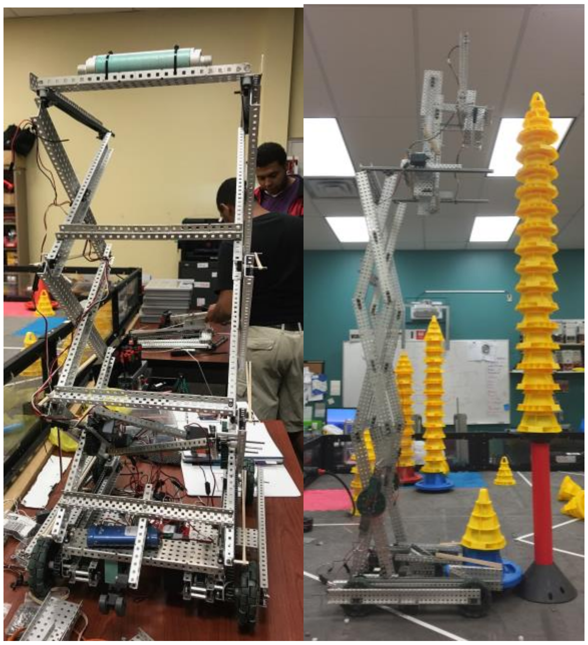


Figure 9. Iteration Two of the Scissor Lift

B.4 Iteration Three

After conducting several functionality tests, the robot began to raise and drop unevenly. It was suspected that excessive friction caused the irregular actuation of each side. After further testing, it was concluded that the height of the robot was causing this issue. Subsequently, when the existing three stages were reduced back to two stages, the lift no longer experienced uneven linear motion.

In the final scissor lift design, the four VEX 2-Wire Motor 393 and gears powering the scissor lift were relocated from the inside of the robot to the outside. Moving these components maximized the internal space within the robot, allowing for a more spacious and more efficient mobile goal lift. Aside from repositioning the mechanism that powered the lift, mechanical stops were also added. The mechanical stops prevented the scissor lift from closing excessively, and this protected the shafts in the gearbox from deformation.

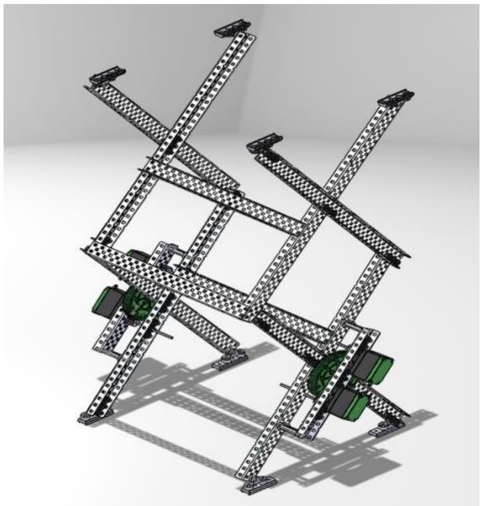


Figure 10. CAD of Motors Mounted on Outside of Scissor Lift

B.5 Rubber Band Assist

To increase the speed of the scissor lift, approved #64 rubber bands by VEX Robotics, were added to the connection points of the lift. On each stage of the lift, two rubber bands were added on both sides. It was understood that rubber bands abided by Hooke's Law. The force a rubber band exerts at the joints of each stage when stretched was calculated by gaining the spring constant of the rubber band and multiplying it by the displacement. To calculate the spring constant, k, a single rubber band was hung from a hook, and the length was measured. Next, weights were added to the other end of the rubber band to get the displacement, shown in Figure 9. The foreseen disadvantage of using rubber bands to help aid the motors was after each match the rubber bands needed to be replaced. Even though a new rubber band could exert 103.879N of force (11) aiding in the actuation of the lift each cycle of expansion and contraction of the rubber band reduced the output force exponentially.

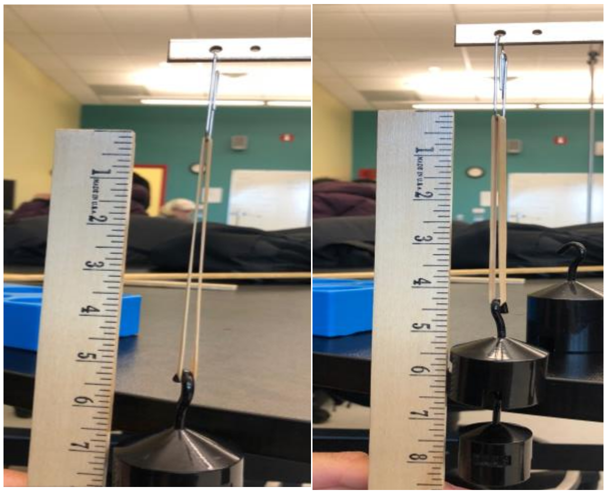


Figure 11. Rubber Band Analysis with 500 grams and 300 grams, respectively.

$$k = \Delta N/\Delta L \tag{7}$$
$$k = (4.9N - 3.92\ N)/(0.015875m - 0.0127m)$$
$$k = 308.66\ N/m$$

$$F = k\Delta L \tag{8}$$
$$F = (308.66N/m)(0.33655m) = 103.879\text{N}$$

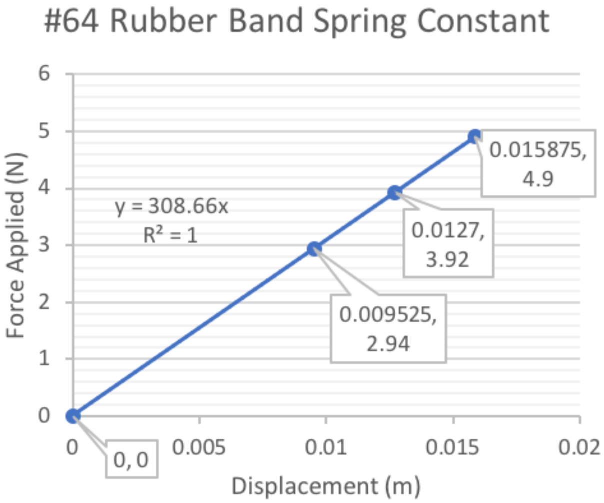


Figure 12. Forced Applied vs. Displacement on #64 Rubber Bands

B.6 Protection

After several successful matches, it was noticed that occasionally cones would fall into the internal frame of the robot. This would occur if the cone were not correctly aligned with the mobile goal. Cones stuck in the structure of the robot is match affecting. For two reasons, it prevents the robot from extending the scissor lift, and it is illegal for the robot to possess more than one cone at a time unless it is placed on a mobile goal. To solve this issue, an anti-slip mat was utilized on the scissor lift, as seen in Figure 11. The anti-slip mat was cut to a length that allowed the mobile goal and scissor lift to extended fully without any restriction. This minor addition substantially increased the robot's efficiency.

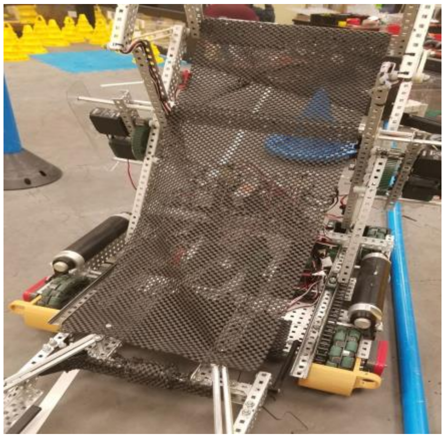


Figure 13. Anti-Slip Mat Protection on Scissor Lift

B.7 Intake

The intake is located at the top of the scissor lift. The intake mechanism needed to be lightweight and fast. To do this, a 3d part replaced the metal that attached the intake to the scissor lift, which can be seen in Figure 12. Another way weight was reduced was by cutting the metal C-channel in half. After testing it was found that the full C-channel and the half C-channels had the same rigidity. The intake is a four-bar mechanism that is powered by a high-speed motor with a 1:5 gear ratio. When doing calculations, it was found that using a high-speed motor with the 1:5 gear ratio would be the best combination as seen in (13-15). To increase the speed of the intake #64 rubber bands were added to the intake allowing for the intake to reach its full potential for speed.

Gear Reduction = Driven Gear Teeth / Driving Gear Teeth = 84 / 12 = 5 (13)
Output Torque = (1.04 N-m) (5) = 5.2 N-m (14)
Output Speed = Input Speed / Gear Reduction = 160 RPM / 5 = 32 RPM (15)

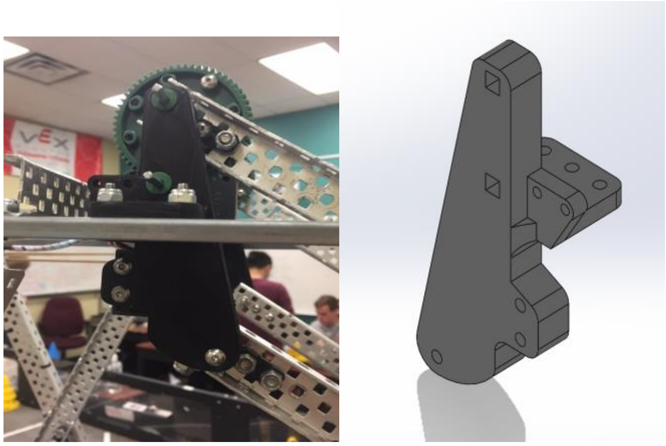


Figure 14. 3D Printed Connection (Actual and CAD model, respectively)

B.8 Claw

In the VEX Robotics competition, each robot is limited to the use of twelve motors. After distributing the motors out across all mechanisms on the robot, it was decided that pneumatics would power the claw as it was only losing 19.15kPa per actuation (12). The claw design was created to have a good grip on the cone. This is important because when the robot is moving fast to stack the cones, there is a chance of the claw incorrectly grabbing the cone. The more surface area there is, the less likely that will happen. Even though the piston was able to exert a linear force of 54.16N at 0.689479 MPa (13), to prevent slipping, the claw was wrapped in an anti-slip mat, which prevented a majority of the slipping.

The claw is connected to the four-bar intake by another part that was 3d designed. This part holds the claw along with the 3d printed piston mount. The piston mount holds the piston that actuates the claw. The assembly of the claw can be seen in Figure 15.

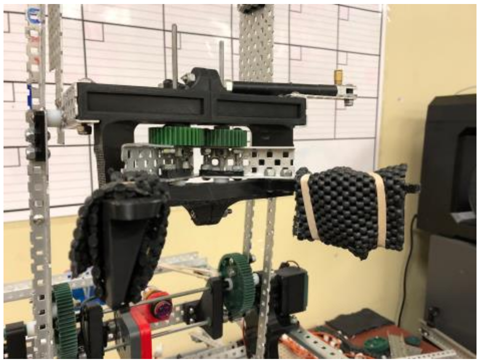


Figure 15: Claw Assembly on Robot

Total actuations = System kPa / kPa loss per actuation (12)
689.479 kPa / 36 actuations = 19.15 kPa loss per actuation

F = (Cross Sectional Area) (Pressure) (13)
(Diameter/2)^2 x Pi = Cross sectional area of piston
(10mm/2)^2 x Pi = 78.54mm^2
(78.55mm^2) (0.689479 MPa) = 54.16 N
Output force =54.16N

C. Automation

The first forty-five seconds of the match is called the autonomous period. In this period teams pre-program their robots to complete the challenge without the use of the remote. For the scissor robot, the autonomous programmed on the robot is as follows: The robot will grab a cone that is pre-placed into the claw and then drops it on to the stationary goal right in front of it. Next, the robot will turn right and head for the mobile goal on the side perimeter. Once getting the mobile goal the robot will align with the pre-load mount on the side of the field where it will attempt to stack seven preloads. Lastly, the robot will head towards the zones and place the mobile goal in the 20-point zone. The robot executing this program properly and getting a higher score than the other robot will be awarded an extra 20 points. The autonomous program can be seen in Figure 16.

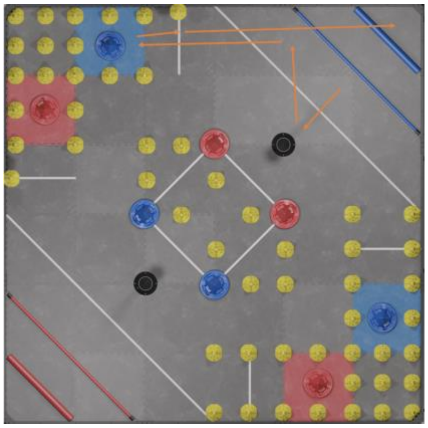


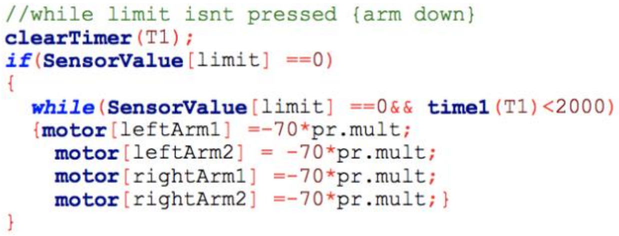
Figure 16. Autonomous Routine

C.1 Line Sensor

Line sensors are used when the robot is lining up to retrieve the mobile goal. The robot follows the diagonal line, that is pre-placed, on the field before attempting to grab the mobile goal. To get the readings from the line sensor to be more precise there are three-line sensors on the bottom of the robot that is directly in the center.

C.2 Limit Switch

A limit switch was also added to the scissor mechanism. It was positioned on the rear right corner of the first stage scissor lift. The limit switch allows the autonomous robot to understand when the scissor lift is extended or when it is fully collapsed. The implementation of the limit switch can be seen in the code in Figure 17.



```
//while limit isnt pressed {arm down}
clearTimer(T1);
if(SensorValue[limit] ==0)
{
  while(SensorValue[limit] ==0&& time1(T1)<2000)
  {motor[leftArm1] =-70*pr.mult;
    motor[leftArm2] = -70*pr.mult;
    motor[rightArm1] =-70*pr.mult;
    motor[rightArm2] =-70*pr.mult;}
}
```

Figure 17. Limit Switch Code for Autonomous

C.3 Gyroscope

For autonomous programming, the robot has a gyroscope sensor that can be found in the center of the robot on the drivetrain. This sensor allows for the robot to make consistent turns. The gyroscope is different from the encoder because instead of measuring the rotation of the axle it instead measures the rotation of the robot.

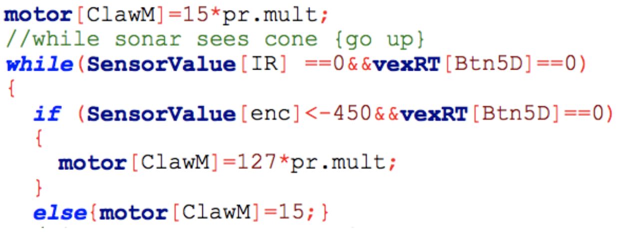
C.4 Encoder

Encoders are executed both on the drivetrain of the robot and the scissor mechanism. Encoders allow the program to determine the rotational speed of the shafts as well as calculating the distance traveled. When implemented on the front wheel shaft, optical shaft encoders provide navigation control. If the robot veers in any direction other than straight, the encoders provide the robot with enough data to allow the robot to increase or decrease the speed of either side of the drivetrain.

Furthermore, the encoders used on the scissor lift are mounted directly to the motors of the power system, and they are known as integrated encoder modules. Even though the functionality of both integrated encoder modules and optical shaft encoders are the same, integrated encoder modules were chosen since they consume less space. The encoders on the power system of the scissor lift help erect the scissor lift evenly the same way the encoders help the drivetrain travel straight.

C.5 Infrared Sensor

The infrared sensor is used for stacking the cones in the autonomous period. The sensor is placed at the top of the scissor lift in the center. This sensor detects when there is a cone in front of it by emitting an infrared wave and measuring the time it takes for the wave to return to the sensor. If there is a cone in front of the sensor tell the robot that the scissor lift needs to expand more before dropping the next cone. Below the code for the infrared sensor can be seen in Figure 18.



```
motor[ClawM]=15*pr.mult;
//while sonar sees cone {go up}
while(SensorValue[IR] ==0&&vexRT[Btn5D]==0)
{
  if (SensorValue[enc]<-450&&vexRT[Btn5D]==0)
  {
    motor[ClawM]=127*pr.mult;
  }
  else{motor[ClawM]=15;}
```

Figure 18. IR Sensor Autonomous Code

IV. CONCLUSION

The robot constructed consists of many different innovative features to accomplish the tasks given in this challenge. The robot consists of an ‘H’ drivetrain powered by six high-speed motors with a 1:1 gear ratio. Inside of the drivetrain is the mobile goal lifting mechanism, that is a four-bar powered by one low-speed motor with a 1:5 gear ratio. On the top of the drivetrain is the cone stacking mechanism, a scissor lift, that is powered by four high-speed motors with a 1:7 gear ratio. At the top of this mechanism is a four-bar intake with a pneumatic claw that picks up the cones. After six months of development and testing, this robot has become a top-class robot that has outperformed other robots on multiple occasions.

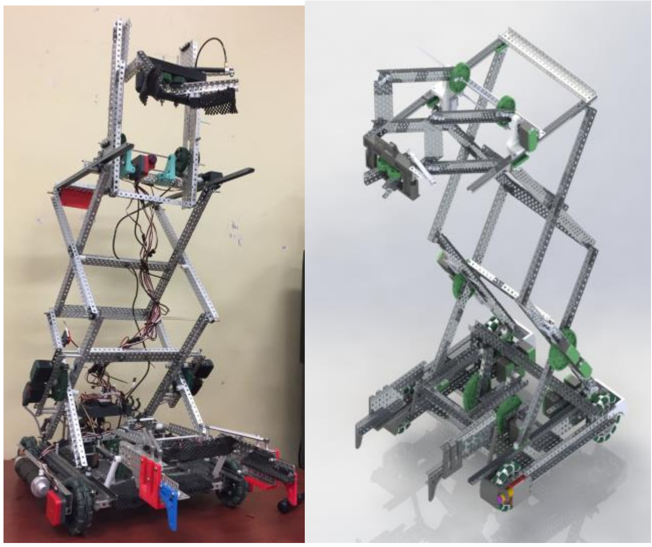


Figure 19. Completed Robot (Actual and CAD model, Respectively)

V. IMPLEMENTATION AND OUTCOME

Since the creation of the scissor robot, it has competed in three competitions including one international, one scrimmage, and one regional qualifier. The innovative robot design made Vaughn College's Robotics team the 2017-2018 tournament champion at Torneo VEX - Reeduca de la Zona Noreste 2017-2018 (Tampico, Mexico), VCAT VEX-U Fall Scrimmage (Queens, NY), and VCAT VEX-U Regional Qualifier (Queens, NY). After winning tournament champion in the VCAT VEX-U Regional Qualifier Vaughn College’s Robotics team received an invitation to participate in the 2018 VEX U World Championship.

At the VEX U World Championship, the largest robotics competition in the world, there will be 84 college teams from around the world competing for tournament champion. Each team will compete in 11 qualifying matches against the top teams in the world. Following the qualifying matches are the quarterfinals, semifinals, and finals.

Figure 20. Vaughn College Robotics Team at VCAT Regional Qualifier

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