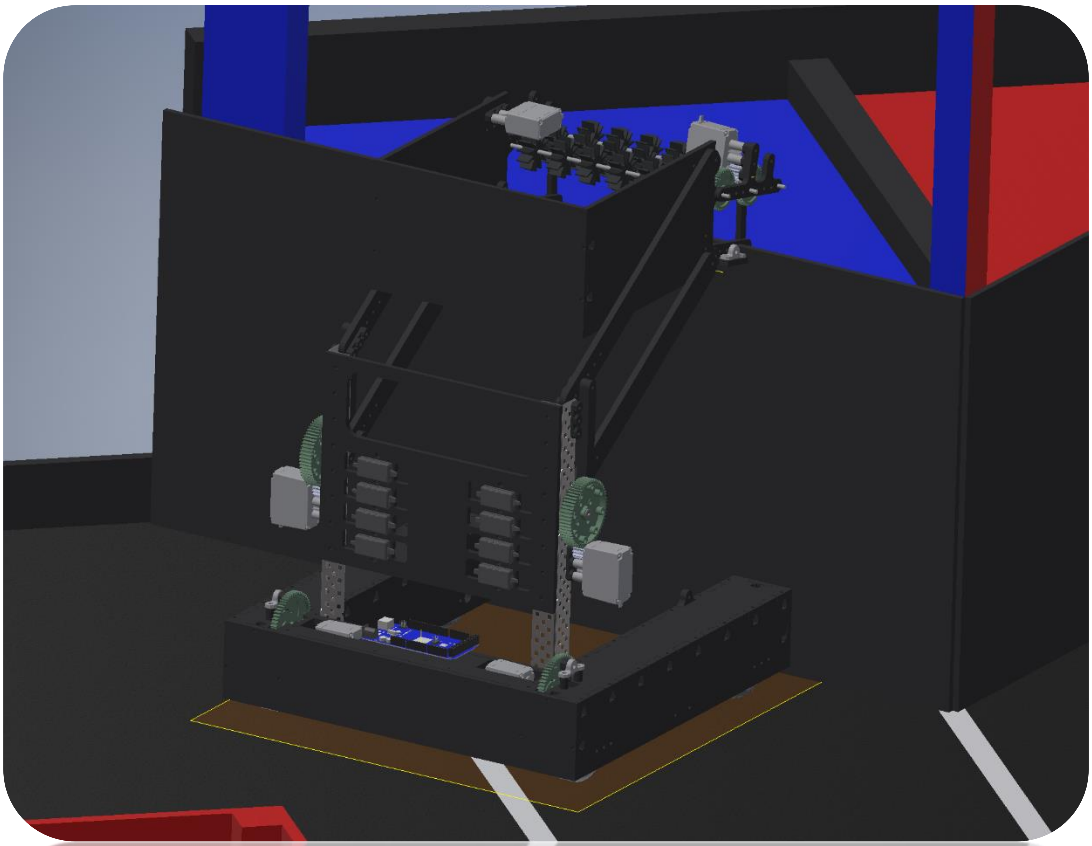
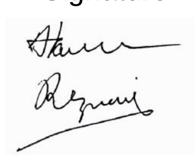
RBE 1001 D 2017: Introduction to Robotics

Final Project Report



Team I: Iguanas that Fly

Member	Signature	Contribution
Alex Tacescu		60%
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Grading: Presentation _____/20
Design Analysis _____/30
Programming _____/30
Accomplishment _____/20
Total _____/100

Table of Contents

List of Figures

List of Tables

1. Introduction

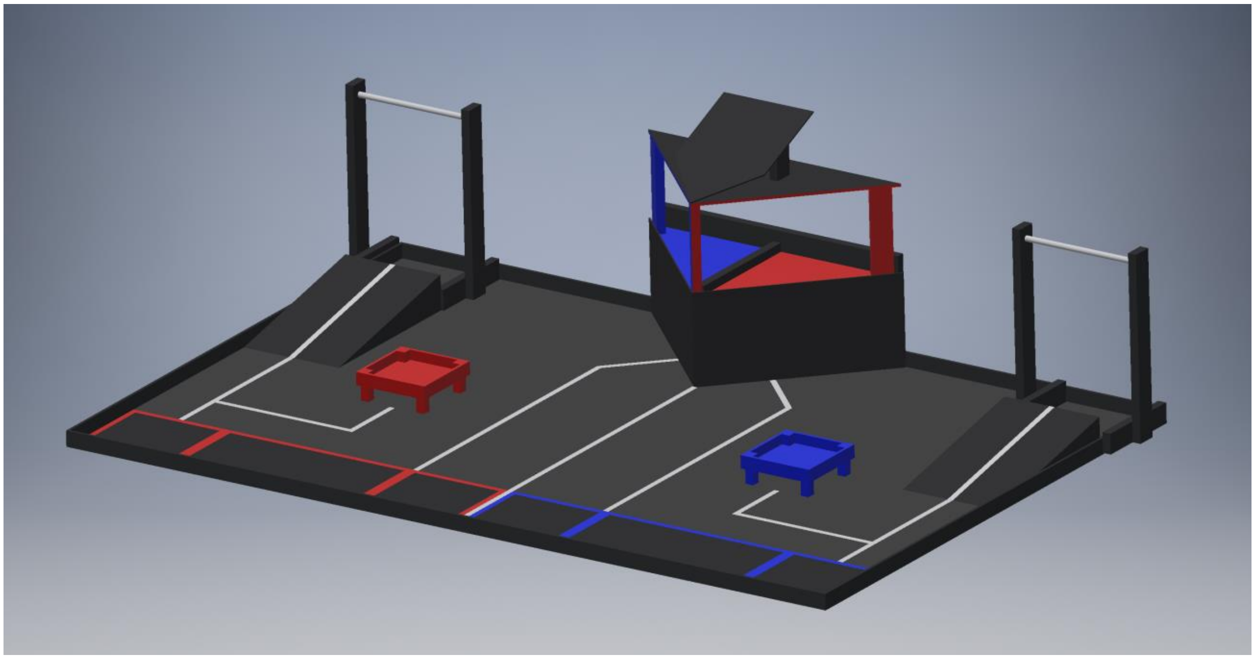


Figure 1 3D CAD of Game Field

We were given the task to design, build, and program an autonomous and teleoperated robot capable of working with another robot to collect and place eggs in scoring containers. Robots begin in the starting box at the beginning of the match, where autonomous begins. After 20 seconds, teleoperations (tele-op) begin, where students take control of the robot (120 seconds). The task is to pick up the EGGs (EGGcellent Game Gizmo) from around the field and place them in one of 3 goals: the COOP (Coalition's Ordinary Object Plane), the PEN (Portable EGG Nest), and the NEST (Nested Elevated Scoring Triangle). Each is a worth a different amount of points. In autonomous, eggs are worth 1 in the COOP, 3 in the PEN, and 6 in the NEST if 2 or less eggs are scored during the time period. However, if you score more than 2 eggs per coalition in the time period, the points per egg are doubled. This means that either one of the robot needs to pick up EGG(s) during autonomous and score it to get double points per eggs.

After autonomous ends, the teleoperated period begins with the referee dropping 36 eggs on the RAD (Referee Assisted Dispenser), scrambling the eggs on the field. At that point, robots have two minutes to collect as many eggs and score them in the designated goals (COOP, PEN, and

NEST). Each egg is worth 1 point in the COOP, 3 points in the PEN, and 6 points in the NEST. The total score will only be counted at the END of the match. During the teleoperated period, teams must switch drivers in the middle of the game. Robot Construction Requirements are listed in the rules. At the end of the match, teams also have the option to hang on the PERCH (Pretty Elevated Robot Communal Hanger) for an extra of 30 points. Also for each robot that is not touching a carpet, 5 additional points are added.

2. Preliminary Discussion

There are several different strategies we have looked at. The first and foremost step was to read the rules several times (to fully understand the game) and then organize the different ways of receiving points. Below is a table with the different ways of scoring within this game:

	Point Values	Description
1	5	Robot in other starting configuration
2	5	Robot fully supported by RAMP
3	5	PEN outside its starting zone
4	1 / EGG	EGGs scored in COOP (<=2 EGGs Scored)
5	2 / EGG	EGGs scored in COOP (>2 EGGs Scored)
6	3 / EGG	EGGs scored in PEN (<= 2 EGGs Scored)
7	6 / EGG	EGGs scored in PEN (> 2 EGGs Scored)
8	6 / EGG	EGGs scored in NEST (<= 2 EGGs Scored)
9	12 / EGG	EGGs scored in NEST (> 2 EGGs Scored)

Max Points
2 -> 8 -> 1 or 2 70pts

Table 1 Possible points in Autonomous

	Point Values	Description
1	1 / EGG	EGGs scored in COOP
2	3 / EGG	EGGs scored in PEN
3	6 / EGG	EGGs scored in NEST
4	5	Robot not touching the carpet
5	35	Robot only supported by PERCH

Max Points
3 -> 5 251

Table 2 Possible Points in Teleoperated Period

One strategy we thought about includes a robot taking an egg and putting it into the nest and repeating this process. However, this method would take a very long time to gather a significant amount of points. Another approach is to as many eggs as possible through an accumulation device and deposit all of them at once. This takes ‘back and forth’ part of the first method, but requires a more complex system to be able to intake EGGs and lift them up to the desired level.

For the autonomous section, there are different ways of gaining points. One method is to drive from one starting zone to another starting zone which results in 5 points. Another way is to go on the ramp which results in 5 points. Finally, the last way is to completely move the PEN away from its initial location and gather all the eggs that are underneath the PEN. Scoring those eggs will get you extra points per egg.

3. Problem Statement

Our main goal is to get as many EGGs as possible all at once before dumping them into the NEST. We start off in autonomous by picking up the EGGs underneath the PEN while moving the PEN from the starting configuration. We are not going for the scoring zone or the ramp for points. Instead, we plan on planting ourselves by the RAD. When the EGGs drop, most will land in our robot. We decided on this because getting to a set configuration gives you a total of 5 point, but scoring an egg in the NEST (our target) gives us 6 points. Therefore, even if only one EGG lands in our robot, our strategy would prove worthwhile. During the teleoperated period, our strategy stands: pick up as many eggs as possible and score them into the NEST.

During the autonomous period, our priorities are as follows:

1. Drive to the PEN using a combination of line follower sensors, gyroscope sensor, and VEX encoders
2. Push the PEN out of its initial area while intaking all the EGGs from underneath
3. Score EGGs into the PEN
4. Move to under the RAD to intake falling EGGs at the beginning of the match

During the teleoperated period, our priorities are as follows:

1. Intake as many EGGs as fast as possible (we call it the Hoarding Strategy)
2. Use a four bar linkage to raise the eggs to the NEST
3. Dispense EGGs into the NEST with assistance of the intake (running backwards).
4. Repeat 1-3 until most EGGs are scored
5. Near the end of the match, push the PEN into the COOP to get extra points (if not taken up by our coalition partner)
6. Drive up the RAMP and wait for match to end.

4. Preliminary Designs

We reviewed the rules and the limitations of the competition and designed our robot accordingly to gain the most possible number of points by using the most efficient strategy. With this in mind, there are 3 main categories: Intake Mechanism, Lifting Mechanism, and Drive Train.

Intake Mechanism

We want to intake EGGs in as many configurations as possible. We decided to try the VEX Intake rollers and made a proof of concept prototype. Below is the picture of our prototype.

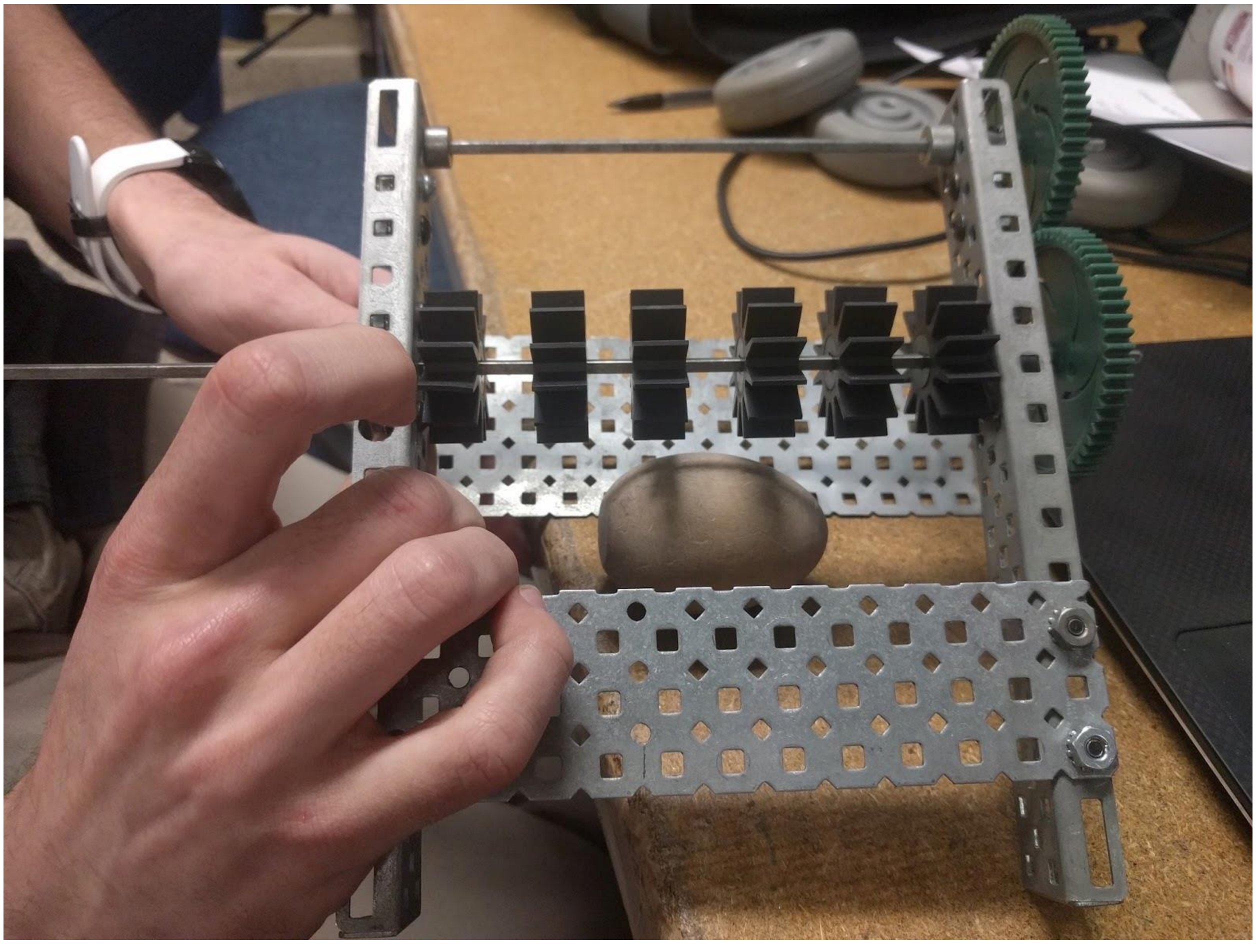


Figure 2 Picture of our Proof of Concept Prototype in Action

Our prototype was very successful, and we therefore went on to sketching up the design. The prototype taught us a few things. First the rollers closest to the ground need to be ahead of the ramp, to start the initial push of the incoming EGGs. Second, speed was absolutely a factor - the faster the speed of the rollers, the better. We did try this with a hand drill, so we still need to consider the overall torque when intaking the EGGs. Below is a drawing on CAD of a possible intake design

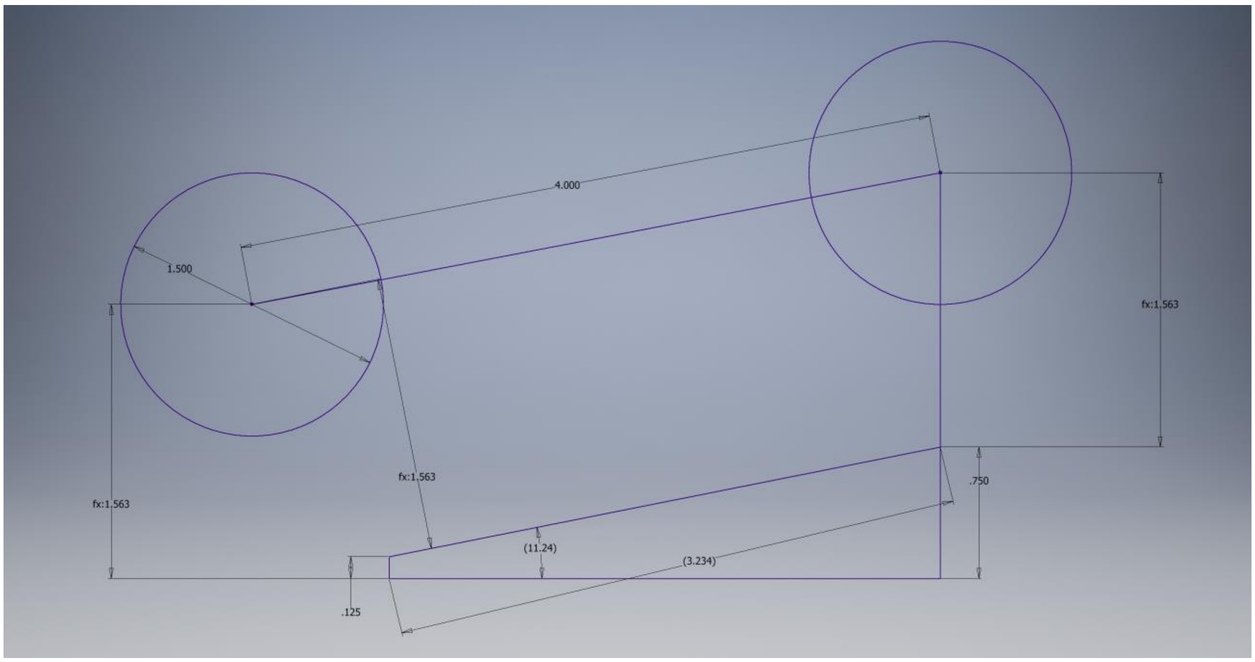


Figure 3 Initial CAD Drawing of the Intake

Lifting Mechanism

When brainstorming, we came up with 2 main ideas: a four bar mechanism and an elevator.

Pros of 4-bar	Cons of 4-bar	Pros of Elevator	Cons of Elevator
- More stable at high levels - Simpler to design (less to go wrong - Reduces torque on driving motors	- Circular bucket trajectory	- Straight bucket trajectory	- High chance of jamming at high levels - More force on robot parts - Need a 2-stage elevator

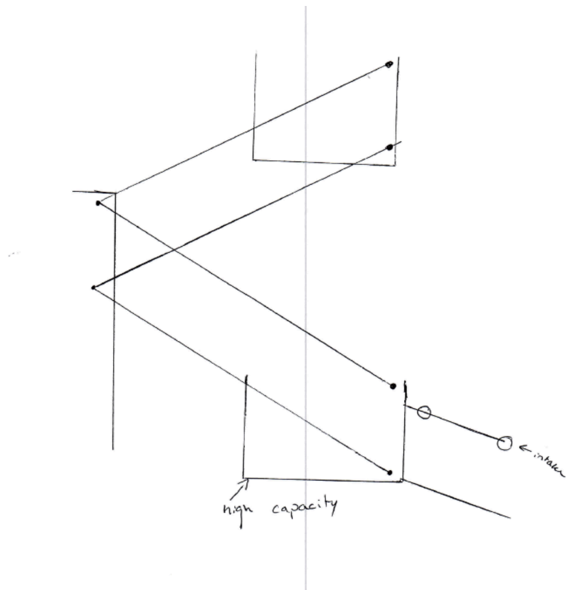


Figure 4 Simple Four Bar Linkage System

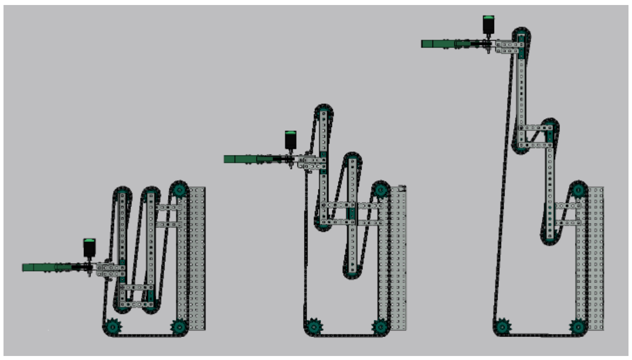


Figure 5 Multi-Stage Elevator Idea (by VEX)

Drive System

To fit all of our mechanisms as well as to more efficiently intake the EGGs, we looked at a U-shape drive frame design. The two options we had for driving the wheels were a 4-wheel drive or a 2-wheel drive. Our best idea was a 2-wheel drive robot with the rubber driving wheels in the back and non-driven omni-wheels in the front. The advantages would include almost zero turning friction, and better control over the mass of the robot (the u-shape frame would put the majority of the mass on the back wheels). The disadvantages would be uneven distribution of traction.

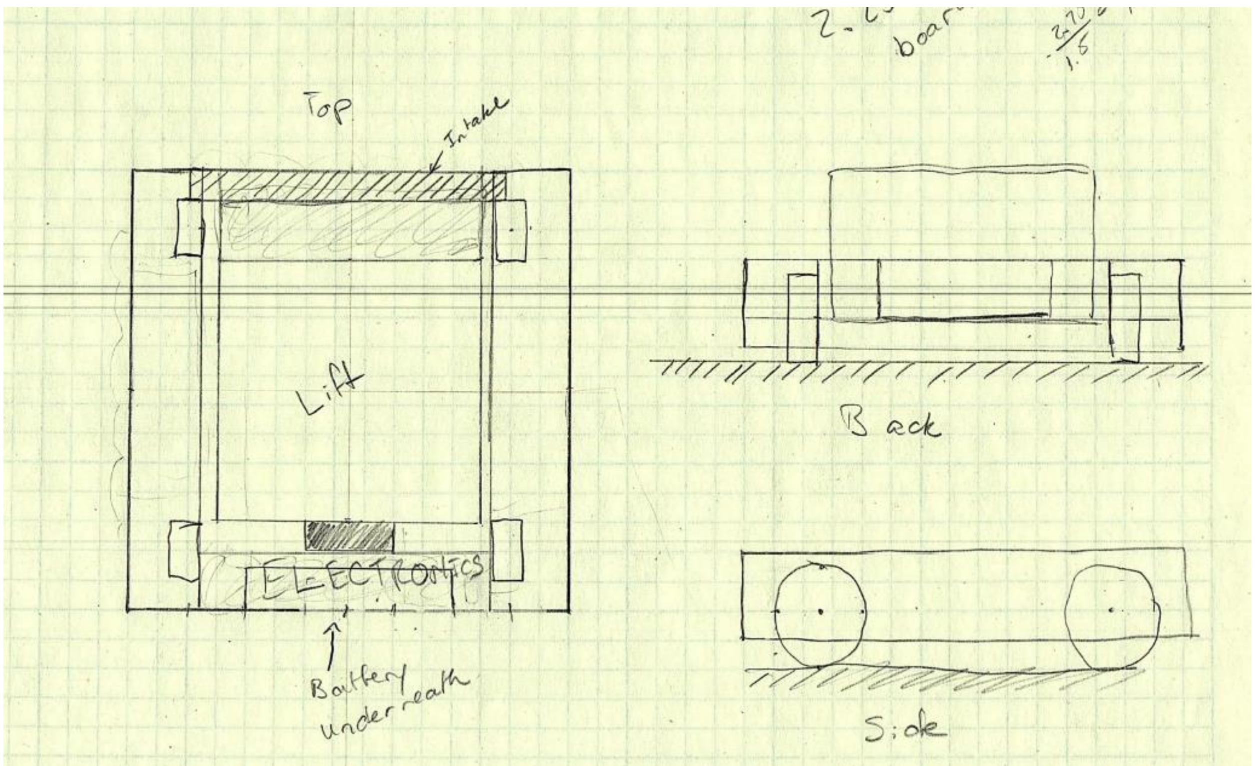


Figure 6 Initial Sketch of a Drive System

5. Selection of Final Design

Our final design started off with the CAD design of our robot. Most problems were foreseen in the CAD model, meaning we had almost no problem while building our robot. We chose to have 2 four bar systems: one for lifting our EGG box, and one for the EGG intake. We also chose a speedy drivetrain for getting to one place of the field to another quickly and efficiently.

Intake Mechanism

The EGG intake consisted of 2 rollers: one in front of the intake ramp and one behind the intake ramp. The sole job of the front intake roller is to suck in as many EGGs as fast as possible. Therefore, it is geared at a 1:1 with a VEX 393 motor running at 100 rpm. The back roller has the purpose of making sure the eggs get in and out of the EGG box, without getting stuck.

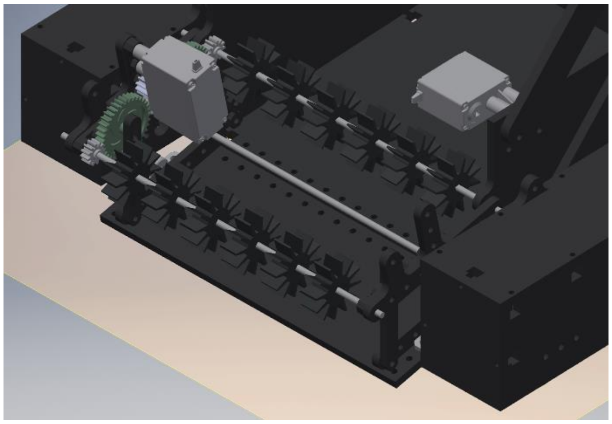


Figure 7 A CAD Model of our Intake System

Lifting Mechanism

As talked about in Section 4, we chose a four bar mechanism as our main lifting mechanism. We chose this mainly because of its improved stability over an elevator when attempting to lift the EGGs in the NEST. The four bar is driven by 2 VEX 393 motors for added torque. The 393 motors are attached to each other by a solid shaft to ensure they are moving at identical speeds, even though they are on opposite sides. Each is attached to another custom gearbox that has a reduction of 5:1, placing the

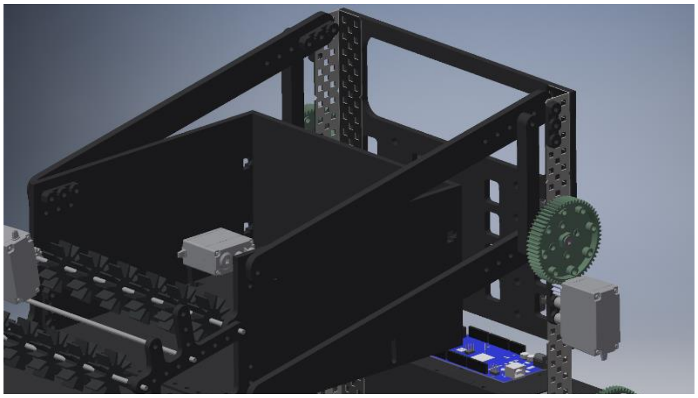


Figure 8 A CAD Model of our Lifting Four Bar Mechanism

driven gear at around 20 RPM (read more about speeds in Section 6).

Intake Lifting Mechanism

The second four bar controlled the EGG intake's capability of folding up and down. It is also geared with a 5:1 reduction, but with chain instead of gears, due to the limited space available. Because we were using plastic chain, we decided to run it with a standard VEX Motor Module, because of the reduced output torque.

Drive System

Finally, for our drive train, we chose to use just one VEX 393 motor on either side geared with a 0.6:1 reduction. This results in an output RPM greater than that of the motor. However, since the limiting factor of the drivetrain was slipping of the wheels, gearing up will only produce more speed, and not reduce our 7+ pounds of pushing force (see Section 6). We placed omni-wheels on the front for little to no turning friction. Also, our robot is only 2-wheel drive to avoid using the problematic plastic VEX chain. This also simplifies our robot, since the virtual turning center is in between the two driven back wheels. Each wheel has a tested coefficient of friction of 1.4, with a bump up to 1.8 when sprayed with WD40, then wiped down after 10 seconds to break down the rubber compound of the wheel.

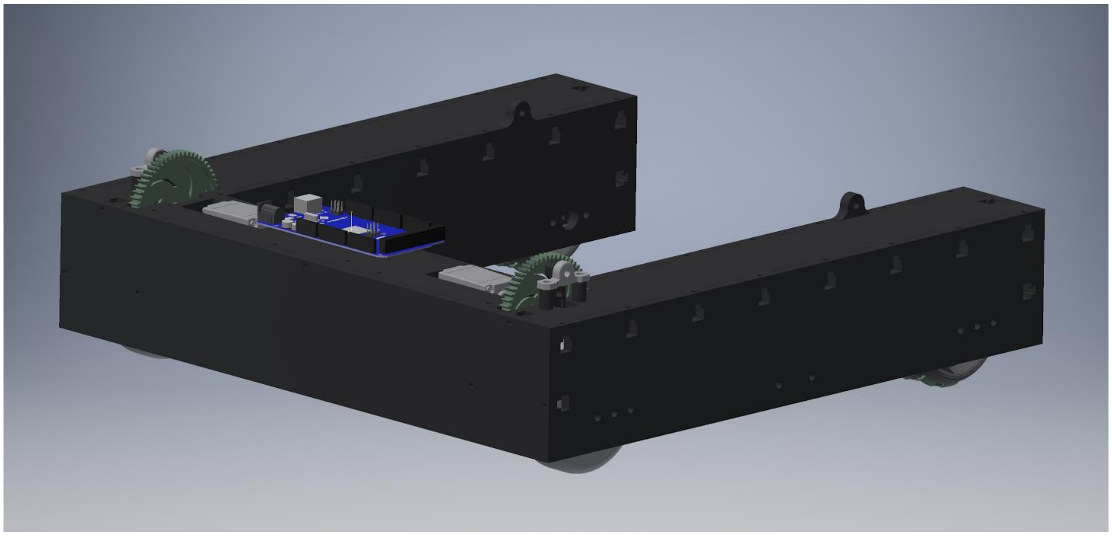


Figure 9 A CAD Model of our Drivetrain

Overall, our robot came to be very successful. It was able to lift every egg possible within a second to the height of the NEST. It reached a measured top speed of 1.5ft/s, and a maximum pushing force of 8.5lbs.

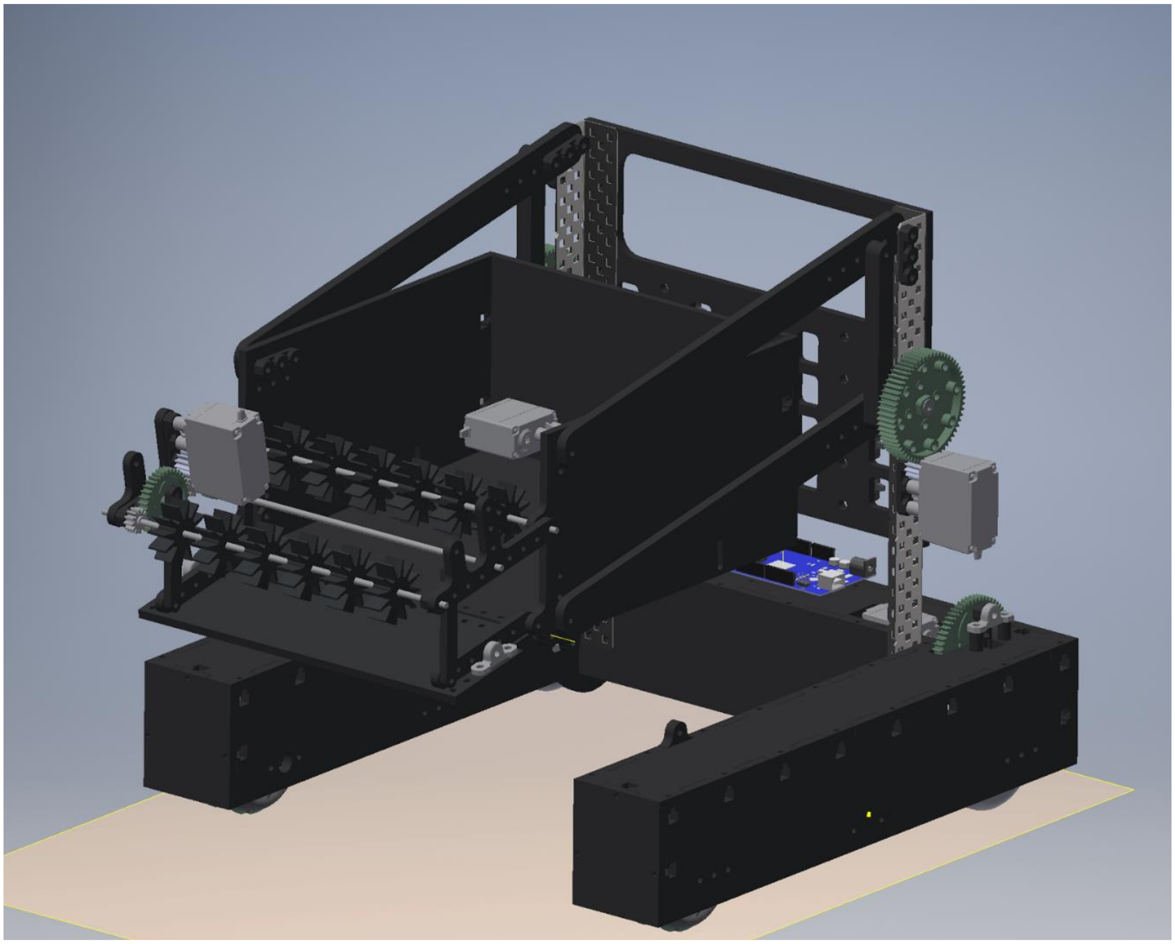


Figure 10 A CAD Model of our Robot

6. Final Design Analysis

Like stated previously, we had designed everything in Autodesk Inventor before building. We therefore had made ALL calculations in the design phase. Thankfully, we also ran into just a few problems when building. The biggest problem was the four-bar mechanism. When designing, we had not thought about how to attach the linkages together. We first decided to just use the standard VEX shafts, but after putting everything together, the system was very shaky and even crooked. We then decided to use 10-24 hardware (washers, nuts, and machine screws) to put everything together. This allowed us to tighten up any loose tolerances that existed in the design. The fix worked wonderfully, and our main four-bar is extremely stable and straight.

Mechanical Analysis of Arm

Our arm needed to lift about 5 pounds of weight in either direction: we designed it to lift absolutely every EGG on the field. We also wanted a speedy lift with only a single reduction gearbox. We therefore decided for a 12:60 reduction, which gives us almost 60in-lbs of torque with two motors. The best part is it is that it takes 1.5 seconds to reach the height required. Below are our calculations:

$$\Sigma F_x = 0$$

$$\Sigma F_y = F_\tau - 5\,lbs = F_y = 0$$

$$\Sigma M_z = 5\,lbs \cdot 11.875\,in - F_\tau \cdot 1\,in = 0$$

$$5\,lbs \cdot 11.875'' = F_\tau \cdot 1\,in$$

$$F_\tau = 59.375\,lbs$$

$$\underline{\tau = 59.75\,in\,lbs}$$

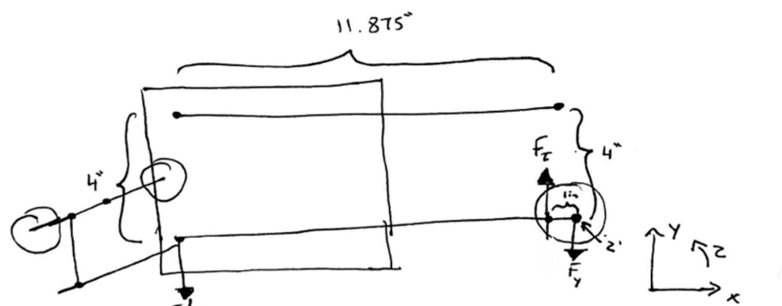


Figure 11 Mechanical Analysis of Arm

2 motors

$$\tau_{out} = 29.69 \quad , \quad \tau_{in} = 6.89\,in\,lbs\ @\ 53rpm$$

$$e = \frac{\tau_{in}}{\tau_{out}} \cdot 0.95 = \frac{6.89\,in\,lbs}{29.69\,in\,lbs}\ 0.95 = 0.22 \quad \checkmark$$

$$12:60 \Rightarrow \boxed{\frac{12}{60} = 0.2}$$

$$e = 0.2 = \frac{n_{out}}{53rpm} \Rightarrow n_{out} = 10.6rpm = 0.177rps =$$

$$= \frac{0.707 \cdot 90^\circ}{s} = \boxed{1.42\,s/90^\circ}$$

Mechanical Analysis of Intake Lift

Our design consists of 1 motor module hooked up to a 12:60 reduction with chain. There were three main reasons for why we used a VEX Motor Module: torque, chain, and weight. We don't need much torque to lift a simple ramp and gears up and down. Also, if we were to use a VEX 393 motor, it would produce too much torque at stall and would break the thin plastic chain we were given. We initially used a VEX 393 motor, which broke the chain. For the analysis, we don't know what the breaking point of the chain. Finally, the VEX Motor Module weighs over 50% less than the 393 motor. Now this doesn't seem like much, especially when the difference is a few tenths of a pound. However, this is placed on our main four bar mechanism, so any reduction of weight helps the main four bar move easier and reduces load on our battery. Below are our calculations:

@ Stall: 4.31 in lbs

$\Sigma F_x = F_\tau - F_c = 0$

$\Sigma F_y = 0$

$\Sigma M_z = 0$

$F_\tau = F_c$

$F_\tau \cdot 0.15 in = 4.31 in lbs$

$\boxed{F_\tau = F_c = 28.73 lbs}$

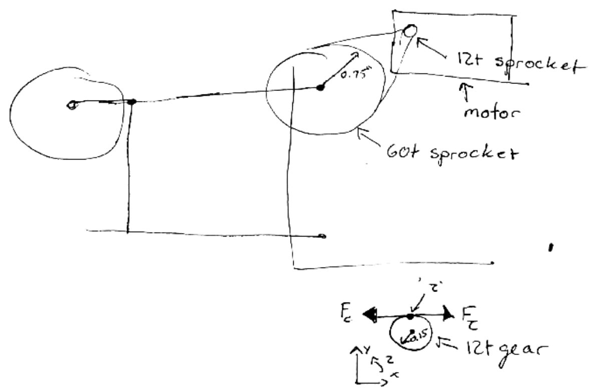


Figure 12 Mechanical Analysis of Intake Lift

Mechanical Analysis of Drivetrain

Our final design has one motor on each side, with a 60:36 reductions. We used a spreadsheet for development, and did the calculations by hand to confirm the results This produces a very fast drive train, up to 1.7ft/s at the wheel. Hand calculations show speed at 100 rpm (free rpm), but the spreadsheet takes care of drivetrain speed loss (at 80%). It also provides a 7 pound pushing force with 50% of the weight of the robot on the wheels and a 1.4 coefficient of friction. We can assume 50% because the center of gravity of the robot is within ±1/2 inches from the center front to back and ±1/16 inches side to side (measured in CAD). The center of weight of the robot depends on positioning of the arm. Below is the spreadsheet output and the drive calculations:

1-Speed Drivetrain Design Calculations

Motor Specs and Drivetrain Parameters

Motor Specs

Applied Voltage (V)	Spec Voltage (V)	Free Speed (RPM)	Stall Torque (N*m)	Stall Current (Amp)	Free Current (Amp)
7.2	7.2	100	1.67	4.8	0.37

Drivetrain Characteristics

Gearboxes in Drivetrain	Motors per Gearbox	Drive Wheel Dia. (in)	Contact Coeff of Friction	Total Robot Weight (lbs)	Weight on Driven Wheels	Speed Loss Constant	Drivetrain Efficiency
2	1	3	1.4	10	50%	81%	90%

Drivetrain Ratios - Individual Stages & Overall Gearing

General Reductions:

	Driving Gear	Driven Gear	Reduction	Comment	Overall Gear Reduction	
Stage 1	60	36	1.6667		**1.6667**	**0.6 : 1**
Stage 2	1	1	1.0000			
Stage 3	1	1	1.0000			
Stage 4	1	1	1.0000			
Stage 5	1	1	1.0000			

Gearbox & Drivetrain Outputs

Gearbox - General Outputs

Max Speed (ft/s)	Max Wheel RPM	Wheel Stall Torque (N*m)
1.77	135.00	0.90

0.6 : 1

Output @ Max Continuous Load

Robot Max Pushing Force (lbs)	Motor Torque Load (N*m)	Current Draw per Motor (Amp)	Total Drivetrain Current Draw (Amp)
7.00	**1.10**	**3.28**	**6.57**

Figure 13 Drivetrain Calculations Spreadsheet

$F_f = \mu \cdot N = 1.4 \cdot 5lbs = \boxed{7 lbs}$

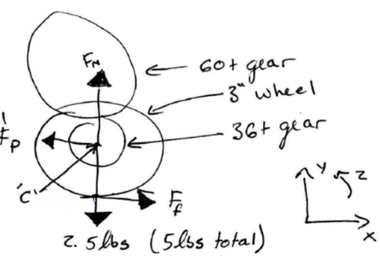
$e = \frac{N_{DVR}}{N_{DVN}} = \frac{60}{36} = 1.67$

Stall: 14.76 in lbs

FreeRPM: 100rpm

$\epsilon = \frac{T_{in}}{T_{out}} \cdot 0.90$

$T_{out} = \frac{T_{in}}{e} \cdot 0.9 = \frac{14.76 \, in\,lbs}{1.67} \times 0.9 = 7.95/wheel$



$\Sigma F_x = F_f - F_p = 0 \Rightarrow F_f = F_p$

$\Sigma F_y = F_N - 2.5\,lbs = 0 \Rightarrow F_N = 2.5\,lbs$

Figure 14 Drivetrain Calculations by Hand

$\Sigma M_{z_c} = F_f \cdot 1.5in = 7.95\,in\,lbs$

$F_f = F_p = 5.3\,lbs \Rightarrow 2\ motors \Rightarrow \boxed{10.6\,lbs\ pushing\ force}$

$e = \frac{n_{out}}{n_{in}} = \frac{n_{out}}{100rpm} \Rightarrow n_{out} = 100 \cdot e = 167rpm \Rightarrow speed = circumference \cdot RPM = 167rpm \cdot 3 \cdot \pi = 1573.9\ in/min = 131\ ft/min = \boxed{2.186\ ft/s}$

$\boxed{2.186ft/s \cdot 0.8 = 1.77ft/s}$

Electrical Analysis

We decided to create 3 custom circuits: 2 buttons and 1 LCD display. The buttons are connected to a ground and digital signal pin. The Arduino is programmed to take care of the pull-up resistor internally to keep the wiring clean. The LCD display is connected directly to the Lab board using Pin 40-45. The buttons will be used to change different modes of autonomous before the competition match starts.

Programming Analysis

Our code went through 2 iterations: a messy iteration designed to test the robot and a final iteration for ease of use and future usability. We use a state machine for the selection of autonomous mode: RedRight, RedLeft, BlueRight, BlueLeft. We wrote 4 classes: Motor, Intake, Lift, and Drivetrain. The Motor class simply will change motor values from -100 to 100, to 0 to 180. This allows for ease of use when programming the variety of methods needed to successfully program a robot.

The Lift and Drivetrain class utilizes a PID library to ensure speed and position. The Drivetrain class uses PID for distance calculations in autonomous, as well as RPM calculations for easier and more accurate driving during teleop. On the other hand, the Lift class uses PID with a potentiometer to calculate the angle of the four bar linkage. This allows the motors to not only accurately get to a set angle but also to stay at that angle.

Finally, the Intake class holds two different jobs: controlling the intake rollers and controlling the intake lift four bar mechanism. This allows for ease of use when programming autonomous and teleoperated modes, although it is not as usable in the future.

7. Summary/Evaluation

All in all, our robot performed mostly as expected, especially with the timeframe given to us. We successfully were able to pick up EGGs and place them in either the PEN or the NEST. We also were able to go up the ramp and catch the falling EGGs at the beginning of the match. We didn't have enough time to perfect the Autonomous mode and pickup and place EGGs in the PEN, even after the Critical Design Review(CDR).

We made few physical changes to the robot after the CDR; however, the same cannot be said about the robot's code. After the CDR, we completely overhauled the code to use classes and objects. We thought this would be a great idea because our code is now reusable in future RBE classes. For example, we can completely reuse the drivetrain and motor classes written for this class (See code in Appendix).

We also tested the limitations of our robot. We observed a max speed of about 1.75ft/s, which is very close to the estimated speed calculated in Section 6. The robot's lifting mechanism was able to comfortably lift itself, albeit when the gears didn't jump. The intake system could definitely be improved, but was overall working as intended. The intake's lift motor had to be running at a reduced speed so it would not snap the chain. We ended up finding the chain's snapping point at around 18lbs. Although the obvious idea would be to reduce the reduction, we could not do that because we were trying to attach the gear at two points, meaning that the radius had to be greater than ½ inch to accommodate two screws. Reducing the power in code worked beautifully, especially because the power needed to lift and lower the intake is minimal.

Although successful, our robot had many shortcomings. There were a few basic design and calculation mistakes. One of the biggest calculation mistakes was the clearance between the rollers and the EGGs. This was solved by adding zip ties on top of the intake rollers, but nonetheless it was a calculation mistake. We also noticed a few parts breaking at key corners. By the end of the Optional Extended Display (OED), the bottom of the carrier had broken at the corners, meaning the bottom ended up only being held by 2 screws on one axis. We solved this by tightening the screws more so that the bottom wouldn't move, but the solution was far from ideal. In programming, there was a bug we haven't figured out with the Distance-based PID. We had coded conversion so that all you had to do is input the distance in inches. However, the calculations were far from off, and we had little to no time to try and fix that. The problem lies in either wheel slipping at the start of autonomous, or a mistake in coding logic.

Other shortcomings that were out of our power were the VEX parts and the battery supplied. The VEX gears often skipped and were not very reliable. Often, we found that we had to use unconventional techniques (like hot glue as a shaft collar) to get everything to work as intended. We also had major issues with the supplied battery. It often ran out of power, and in one match in the OED, didn't have enough power to even run the robot forward. Although having multiple charged batteries would be a solution, the problem was that there weren't enough batteries for all teams to have 2 batteries.

All in all, we are very happy in what we could accomplish in the 2 weeks we had to build a robot. We not only fully designed our entire robot in CAD before building it, we managed to learn a ton of new skills, from using the Washburn laser cutter to different machines in Washburn and Higgins machine shops, to coding classes in C++. For a two-week effort, we are both really proud of our EGGcellent robot.

8. Appendix

Code can be found at https://github.com/alextac98/RBE-1001
Final_Robot_Code is the final robot code, *CDR_Robot_Code* is the code at the CDR.

CAD files can be requested if desired.