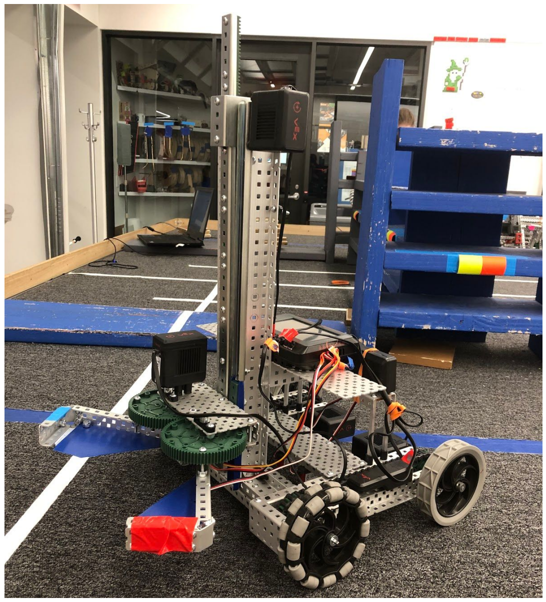
Worcester Polytechnic Institute
Robotics Engineering Program



Team 9

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Student	% Contribution Pre-IDR	% Contribution Post-IDR
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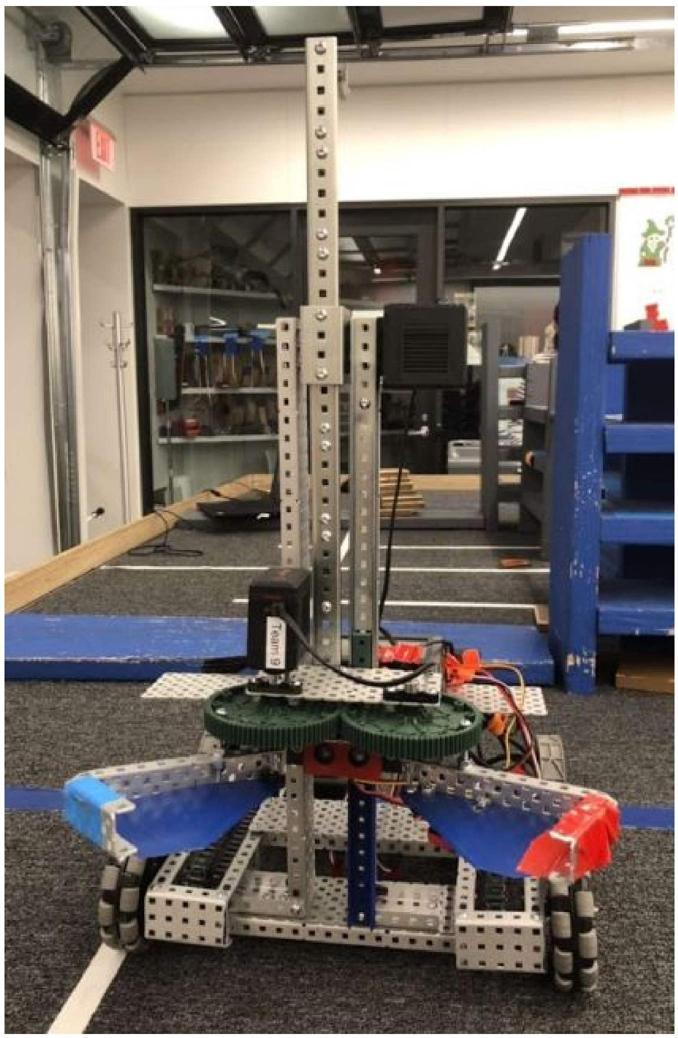
Total	100%	100%

Introduction and Overview

The goal of the project was to design a robot that was able to pick up pizzas, move pizzas around the arena, traverse over obstacles, and place pizzas into the dorms. We were tasked with designing the mechanics to drive and manipulate the pizzas, but also with the ability to control the robot autonomously with sensors and with driver control.

The main functionalities the robot needed to be able to complete are to navigate the arena, intake and hold pizzas, and deliver pizzas to the proper dorms. The main components of our robot was a claw mechanism to intake and hold the pizzas, a rack and pinion used as an elevator to deliver the pizzas to the dorms, and a drivetrain base to move around the arena. We also used sensors (such as the line sensor, ultrasonic sensor, and button sensor) to enable all of our mechanical components to be used to navigate the arena and score pizzas.



Solutions and Justifications

Intake

The ability to directly interact with the pizzas from the ground or bakery was crucial to be able to place them within the dorms. A main functionality of our robot is the ability to intake and hold pizzas. The constraints that are associated with intaking pizzas are that the mechanism needs to be able to securely grip the pizzas, the mechanism cannot stick too far out from the base, the mechanism cannot support more than one pizza at a time, and the mechanism must be able to pick up and discard the pizza.

During the prototyping and testing phase, we considered many designs that could possibly be used to intake pizzas (Figure 1). Other preliminary ideas include a conveyor belt to pick up the pizza from the ground, and a forklift or a shovel like mechanism. The forklift concept was eliminated after we realized the extreme complexity of creating a pivot at one end of the belt. An additional reason we eliminated this idea was because of size constraints; the mechanism would be too large to fit within frame parameters. The conveyor belt idea was eliminated because it would serve as an intake and a pizza transportations method. This idea was not feasible for the dimension constraints due to its size and overall bulkiness of the apparatus.

The two main ideas we considered for the intake were a claw and a roller intake (Figure 2 and Figure 3). The roller intake and claw were both exceptional ideas because the controls were rather simplistic, both mechanisms were modular (so either design could have been easily switched between either lifting mechanism), and both designs were compact enough to reasonably fit into the size parameters of our robot. To decide between the claw and the roller we did a test based on the reliability of each individual mechanism. The claw and intake roller had about equal success rates, which did not prove one intake to be superior to the other (Figure 4 and Figure 5).

The deciding factor was in the robustness of the system. Since the roller intake used long axles, which caused the axles to bend, and the overall design required an excessive amount of parts. We decided that the claw was more effective because the claw was more structurally sound. We decided the claw was superior because there were several different ways to increase the reliability of the claw. For example, we noticed that the claw was continuously dropping plates when the robot was traveling over the speed bump. We added 3D printed base plates to the arms of the claw to help support the weight of the pizza (Figure 6).

Pizza Delivery

The ability to move pizzas off the ground to varying heights is essential to be able to gain points for delivering pizzas. Specific design constraints for the lifting mechanism were designed to achieve maximum capability for our device. For example, the tallest floor for Faraday was around 17 inches tall, so we created a mechanism that was able to reach over 17 inches from the ground. We also required an apparatus that was relatively simple to build and code so we could easily maintain the mechanism. We also determined that the lifting mechanism must be fast enough to deliver pizzas within a timely manner; having a slow lifting mechanism would greatly reduce the cycle time of the robot.

The lifting system we applied was an elevator system (Figure 7). The elevator system was composed of a plastic linear cradle, rack gears, and a linear slide that was driven by a 12-tooth gear. The intake system was attached to the elevator which allowed for height manipulation of the pizza.

During the prototyping process we also considered using a fourbar linkage system and a lifting conveyor belt as a means to lift the pizzas. We considered the fourbar linkage to lack precision due to the excessive amount of lash within the gears; the lash caused the end of the linkage to shift without any input from the motors. The fourbar linkage was also larger than the other mechanisms. Due to the geometry of the device, the fourbar was considerably larger than the elevator prototype. This would limit our ability to use other mechanisms on our robot, such as the aerial delivery apparatus. In addition, we also considered using a lifting conveyor belt. The concept of the conveyor belt was to intake the pizzas from the intake of the belt, and the pizzas would travel to the other side of the belt via the conveyor track, and then the pizza would be delivered to the dorm from the opposite end of the belt that would be raised or lowered according to height requirements. However, this idea proved to be too complicated. The concept of transporting the pizzas by using a conveyor belt was sound, but the aspect of lifting one end of the conveyor belt to an adjusting height proved to be too inefficient and difficult. This method also lacked any method to actively hold or intake a pizza which raised concerns regarding the strength and accuracy of the system.

Ultimately, due to the complexity and the inefficiency of both the fourbar and the conveyor belt, we decided to implement the elevator system. We did not test the capabilities of the lifting conveyor belt due to the complexity of the system. We discovered the fourbar apparatus was lacking; it was unable to reach the height requirement that was necessary to accurately deliver pizzas (Figure 8). Although the elevator was the ideal device for delivering pizzas, it did have mechanical issues. We noticed the elevator tended to sway horizontally; in order to keep the elevator from being unstable, we 3D printed an extension for the linear slide in order to keep the linear slide of the elevator secured (Figure 9).

Deliver Pizzas to Proper Dorm

An important part of the functionality of the robot was its ability to deliver pizzas to the proper dorm. We did this with the use of a similar drivetrain to the one that was designed for the Basebot lab. The main changes we made were to get better functionality and to be able to easier integrate the entire system (Figure 11).

One core functionality was moving around the arena in order to score the pizzas. We accomplished this goal with the drivetrain and the use of sensors to navigate. The changes that we made to the base bot were done to allow better system integration; these changes also contributed to an increase in functionality, like going over the speed bump. A major change we made was the ability to traverse over the speed bump. When first testing the ability of the BaseBot to travel over the speed bump, we noticed that if we drove over the bump with the omni wheels leading and the traction wheels driving in the back with rear wheel drive, the robot would not have enough traction to follow over the speed bump. To change this problem, we added a chain and sprocket to drive both the front and rear wheels; in turn, this lessens the omni wheels tendency to spin out on the speed bump. Another alteration we made to the robot was to the dimensions of the chassis. In order to fit the smallest claw intake on to our bot we had to move the back wheels in order to stay within the frame perimeter. Not only did this help us to stay within our frame parameter, but it also caused us to lose some stability. Stability was lost since the wheels were close together which reduces the base of the robot; thus, the robot was more prone to tip, as described in Matriac chapter 5. Additionally, we couldn't go with the most effective claw design of 10in:10in arms because it compromised the stability of the overall robot, and the arms did not fit within the frame perimeter. However, the 5in:10in arms were a suitable substitution because they performed and functioned extremely similarly (Figure 14).

To reliably deliver pizzas to the right dorm we first had to correctly orientate ourselves in front of the building. Using dead reckoning to align the robot with the dorms was ineffective because we previously traveled over the speed bump; this caused too much variation within the path of our robot which would then completely alter the course of our autonomous mode. Instead, the robot used the line sensor to detect when it reached a white line; It then turned right which positioned the robot to face towards the dorm. After the initial phase of positioning, the robot would then move forward to place the pizza within the dorm. Then the robot uses a switch statement to determine which floor the robot should reach, starting with floor 1. Inside, the case for each dorm begins with a function that lowers the elevator to the floor. The function then uses the button attached to the bottom of the claw to stop the elevator once it reaches the floor. This allows the robot to start from the same position before moving the elevator to each floor set point, this making the position of the intake more reliable. We then have the robot lift the elevator a set distance depending on which floor the switch statement is on. Afterwards, the robot travels forward to dispense the pizza, and travels back to the bakery to initiate the sequence again.

Arena Navigation (Sensors)

One of the major core functionalities includes navigating the arena. This includes using the drivetrain and numerous sensors to move the robot into the construction zone (Figure 10). The robot began in its starting position in front of the blue line across from the bakery. The robot used the ultrasonic sensor in the claw to drive towards the bakery. Afterwards, the robot moves the claw down until the bump sensor on the claw reaches the ground. The bump sensor is the starting point the elevator uses to keep track of a set height and reduce error; the bump sensor effectively zeros the height of the elevator before every use to improve accuracy. The elevator then moves up to the height of the bakery slot. The claw closes slightly, and the robot moves forward a slight distance to intake the pizza. The ultrasonic sensor in the claw is used to detect if the claw is holding the pizza. If so, the robot uses line sensing to drive backwards until it reaches the blue tape on the field, to maneuver back to its original position. Sensing the blue tape via line sensors is the robot's que to turn right and drive forward until it reaches the intersection of the both white tape in front of the speed bump. At this point, the robot turns right and heads towards the speed bump. The robot starts towards the speed bump with a greater velocity, lowers the elevator, pushing itself onto the speed bump. When the robot is on top of the speed bump, the robot slows down and lifts the elevator to get off the speed bump. The chassis of the robot is built with tread connecting the front and back wheels to form a drivetrain. This configuration allows the robot to use the force of the back wheels to get over the speed bump. After successfully traveling over the speed bump, the robot moves forward using line sensors until it reaches the intersection of two white tapes.

The robot would then turn right into the dorm, lift the elevator up so the bump switch isn't dragging. That way the robot is able to reach the height of the dorm level. The robot then opens the claw, reverses backt, and brings the elevator down unit bump switch is activated then raises the elevator to the height needed to get back over the speed bump with the claw still open. The robot then turns right and proceeds to drive over the speed bump. Then the ultrasonic sensor is used to make the robot move forward until it reaches the set distance away from the field's outer edge. It then turns left to drive to the bakery to reach its original starting position in order to deliver pizzas to the other dorm levels. There were a few challenges we faced; one being raising the elevator. As the robot ran through each iteration of the repeating code, the sources of error increased for lifting the elevator. As a result, the height the elevator lifted to deliver the pizzas in the dorms were off on many occasions, as the autonomous code runs in a loop. By adding the button, the elevator was able to determine and lift to the necessary height. The elevator starts at the same position every time, making the code more reliable, as the elevator no longer depended on the previous height/position for the elevator.

Another problem was getting over the speed bump. The omni wheels did not have enough power to do so in the original design. To distribute the power from the back to front wheels, a chain was added (Figure 11). This helped to prevent the front wheels from spinning out as often.

We also increased the angle at which the robot turned right after collecting the pizza and the initial speed required to get up the speed bump. Doing so increased the distance the robot traveled to arrive at the speed bump which allowed the robot to gain more momentum to cross the obstacle. However, errors still occur when passing over the speed bump. For example, the robot would occasionally become stuck when trying to cross the speed bump and would not be able to travel to the other side. To ensure success when crossing the speed bump, we lowered the elevator to help push the robot over the speed bump. This increased the amount of torque within the robot, enabling it to get over the obstacle (Figure 12). Another problem we faced was sensing the white tape after the speed bump. Due to the increased velocity, the robot was moving too fast to sense the white tape percent values and turn accordingly. Additionally, the lowered claw would at times become stuck on the bump, making it more difficult for the robot to move. As a result, we lifted the elevator up and decreased the speed the robot exited the speed bump.

Using the vision sensor to find the dorms was an option that was considered. However, the glare from the lights was not reflecting consistent values for the various colors. Instead, we utilized the line sensors since the path to the dorms were outlined by white tape. When entering the construction zone, we believed that line sensors would be more reliable, as compared to an ultrasonic sensor. This is because the robot may receive inconsistent values due to the large distance between the two objects. In addition, we had to ensure to keep the claw completely open, so the arms of the claw don't interfere with the values being read from the sensor.

When traveling over the speed bump, the robot would begin with a pre-loaded pizza in the intake mechanism. The robot will be placed in front of the speed bump and have it attempt to run over it. This was done 10 times with a pass/fail grading to determine reliability. A pass was defined as if the robot gets completely over the speed bump within 20 seconds with the pizza still held within the intake mechanism. The percentage of successful entries of the construction zone was measured (Figure 13). Its value lies in the robot's ability to reliably go over the speed bump while holding the pizza is a useful way to score points in autonomous and teleop.

System Integration

The main system included the drive train, an ultrasonic sensor, a button, two line sensors, an elevator and a claw mechanism. The ultrasonic sensor was placed between the arms of the claw. Originally instead of using the ultrasonic sensor, we were originally going to use a button attached to the front of the claw at the end of one of the arms as specified in the IDR. However, if we attached the ultrasonic sensor to the inside of the claw it could be used to detect if the robot was nearing a wall and if a pizza could be grabbed. This proved to be extremely effective. The robot used the ultrasonic sensor when positioning itself from the bakery and when traveling over the speed bump. This proved to be reliable during testing as it was able to consistently turn towards the bakery.

Another aspect of system integration was using a combination of the drivetrain, elevator, and claw to maneuver over the speed bump. During the IDR we tested how effective the base robot would be at getting over the speed bump while holding a pizza. As shown in Figure 13 to test this we had the robot hold the pizza at three different heights with the elevator: low, medium and high. For each height we had 15 trials where the robot had to go over the speed bump. The tests showed that the robot was most effective when the elevator was lowered down. Lowering the elevator also lowered the robot's center of gravity making it less likely for the robot to tip over when crossing. From this we were able to ensure we had the proper idle elevator height while running through the competition. However, we eventually found it necessary for the robot to get over the speed bump in a more controlled manner. To do this we decided to use the elevator to lift ourselves on to the speedbump.

For accurately delivering pizzas in the dorm, we tested the reliability of pizza placement on each floor in the dorm Faraday. For each floor, we tested how many times out of 15 trials, the robot was able to correctly deliver a pizza. From the IDR test we found that we had the most success delivering pizzas to the first two floors; this is due to minimal elevator movement when delivering pizzas. Since the first two floors were closest to the ground, time was saved because the elevator did not have to extend as much off the ground.

Performance

The tests from the PDR were mainly focused on the design of the individual mechanisms that were used to address the different functionalities of the game challenges. The PDR focused on testing surrounding the accuracy of the different mechanisms when we changed certain parameters. The four mechanisms we tested were the elevator, the four-bar, the claw and the roller intake. Based on these tests and some other factors we choose to go with the elevator and claw.

For the pizza intake mechanism, we tested the claw and the roller intake with two tests each to determine which one had the best reliability. The tests for the claw included what dimensions of the arms would accurately support the pizza the most. We changed the arms of the claw for the first test; we tested four separate arm dimensions of 10in:5in, 10in:10in, 15in:5in, and 15in:10in. The results showed that the 10in:5in and 10in:10in arms were the best arm lengths (Figure 14). After this test, we used its results to see the effects of a bottom plate of different dimensions on the accuracy of the pizza holding. The test results of the claw intake influenced the decision to add base plate to the bottom of the arms. Since the arms claw was largely ineffective holding the pizza when traveling at fast speeds or over the speed bump, we added additional plates on the claw to help secure the pizza. Not only did the reliability of the claw increase after adding the base plates, but the plates also helped contain the pizza when traveling over difficult terrain. This confirmed our earlier belief that the addition of larger plates to the claw would help increase its ability to pick up and hold pizzas (Figure 15). Although these tests are not as relatable to our final model, due to the addition of a button which prevented us from picking up pizzas from the floor, the plates still helped to almost completely eliminate the issue of dropping the pizzas while in transit. The roller intake was tested for the accuracy of ground pick up based on the speed of the wheels (Figure 17) and the number of rubber bands needed around the rollers (Figure 16) to get the most reliable pick up and hold. The roller intake was just as effective overall, but as stated above the fragile state of the roller mechanism and the ability to increase claw reliability with simple addition like plates, made the claw the clear choice for our design.

For the delivery of the pizzas to the dorm levels we tested a fourbar mechanism and an elevator mechanism that use a rack and pinion. The other idea we considered was a conveyor belt but due to the constraints of the robot, we eliminated this idea immediately after building it. We tested the ability of the four to raise to a specific height and hold that height without gear slippage for different lengths of the fourbar arms. This test concluded that the fourbar would be complicated to control, had less accuracy the higher it extended, and with our robot design it would have taken up a majority of the space within the frame parameter of the robot.

The IDR tests only used the claw and elevator but were more focused on the integration of both devices on to the drivetrain we had previously designed. We tested the accuracy of the whole system of the claw and elevator together to deliver pizzas, the ability of the drivetrain and intake mechanism to go over the speed bump and the accuracy of our aerial delivery mechanism. The test for the speed bump entry showed that we could only enter with our claw at lower heights because if not then we would tip over. This test also showed us how accurate a constant speed construction zone entry was, and that the addition of the chain helped in that area like we theorized it would (Figure 12). We do not have test for with and without the chain but a general consensus from the team was that the chain overall aided in being able to perform more successful entries to the construction zone.

The test we did for the claw and elevator integrated system was to observe how accurate the devices were when working together. This test showed us one major flaw, that this design could not reach the top floors of messenger (Figure 18). Because of the height restriction, we were unable to reach the highest level of Messenger and our robot occasionally had difficulty reaching the top level of faraday. Otherise, the two mechanisms worked well together; spacing adjustments were necessary to properly combine the claw and the elevator mechanisms.

The final test was testing the aerial delivery with the hook mechanism that we had designed (Figure 19). This test became obsolete when we realized we could also use the claw and elevator combined mechanism to do the aerial delivery. Instead of using a new mechanism, we extended the elevator all the way, moved the intake over the bar, and pulled the robot upwards. The IDR test helped us to understand where we needed to improve the integration of the different mechanisms of our robot, and how to integrate different sensors into our robot and how they contribute to the overall functionality of the robot itself.

In comparison to other robots, our robot had trouble picking up pizzas from the ground. The added addition of the button to the bottom of claw prevented the claw from lowering completely to the ground. Our autonomous program varied largely from the other robots. Our robot picked up a pizza from the bakery and drove in the construction zone to deliver the pizzas to various dorm heights. However, during the OED we realized we had to alter our autonomous program so that it does not conflict with the other team's autonomous program. One improvement that could be made to the robot was the speed at which it traveled. If we had more time to test our final iteration of the robot, testing exactly how fast the robot could move for a certain distance without toppling over would be another important consideration for the CDR. Implementing code that would limit our maximum speed could prevent stability issues of the robot, and would make the operation of the robot easier. The ultrasonic sensors, line followers, and bump switch helped improve accuracy and precision of the robot's current and final location. These sensors were beneficial because it allowed the robot to sense its surroundings and act accordingly to a changing environment. Specifically, in terms of sensors and code for the competition, we found the set points for the aerial lift and the dorm levels to be an important asset for the performance of the robot during the CDR and the OED.

Appendix:

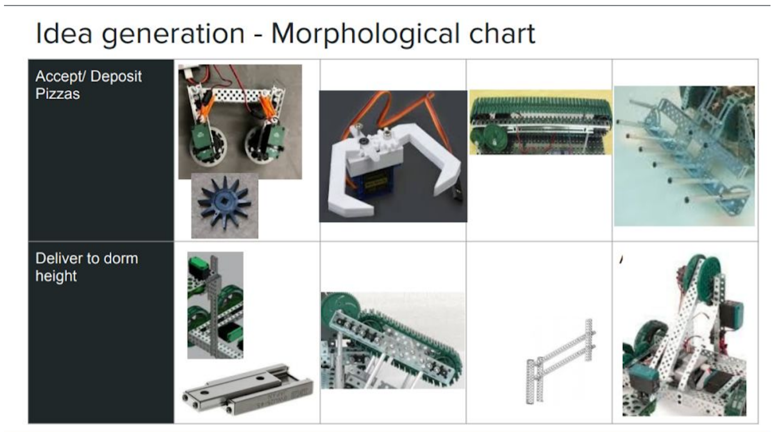


Figure 1
Chart depicting idea generation of the robot

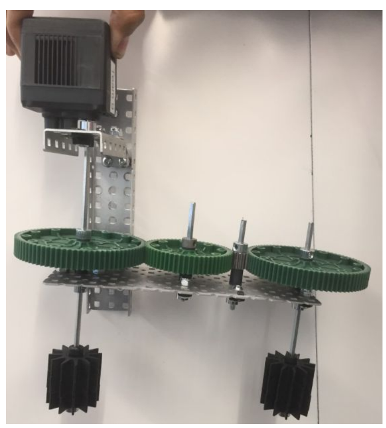


Figure 2
Picture of the preliminary design of the roller intake

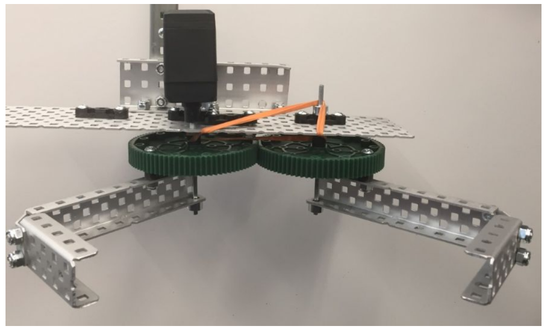


Figure 3
Picture of the preliminary design of the clamp

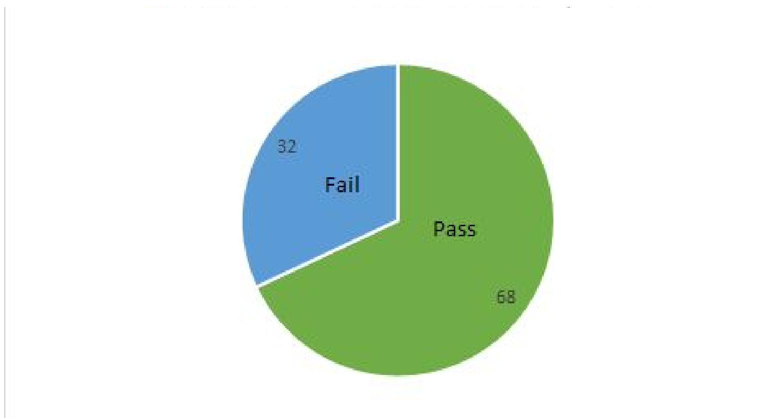


Figure 4
Graph depicting the pass/fail results of the roller intake test

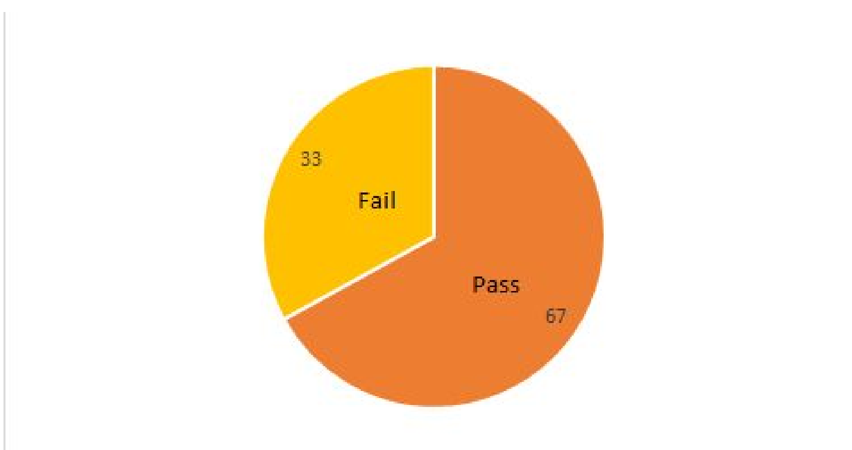


Figure 5
Graph depicting the pass/fail results of the claw

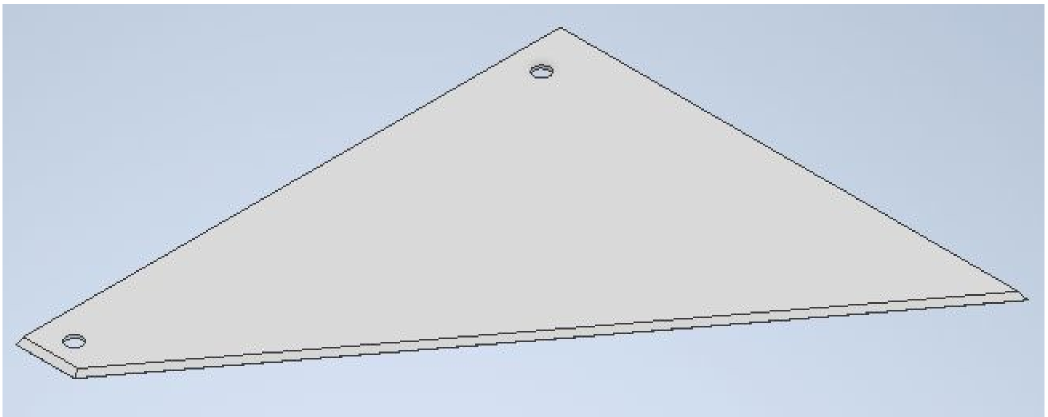


Figure 6
CAD model of the 3D printed base plated for the bottom of the claw

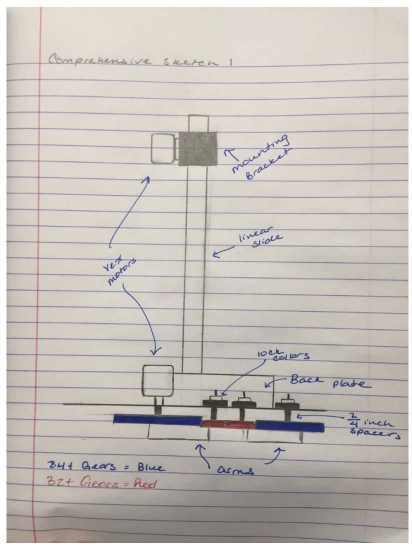


Figure 7
Detailed drawing of the elevator mechanism

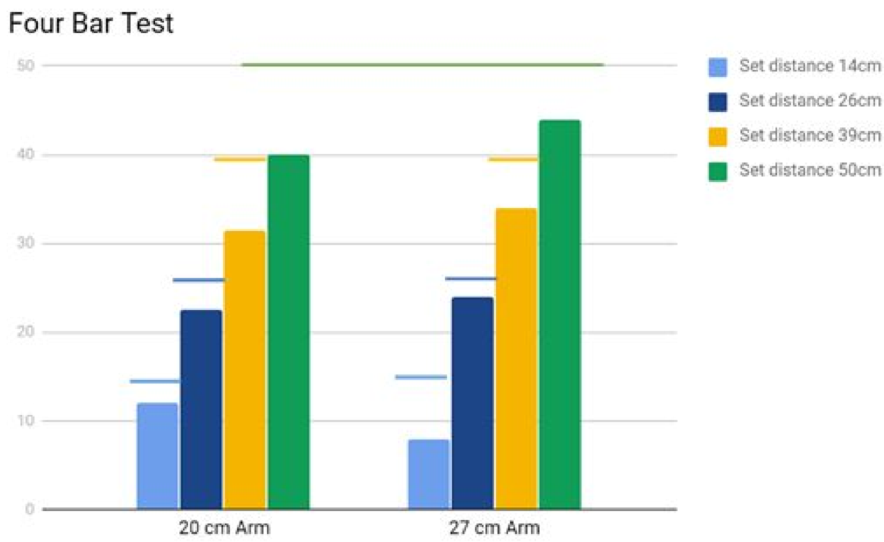


Figure 8
Graph showing the actual reach of the fourbar linkage versus the height that needs to be achieved to reach dorms

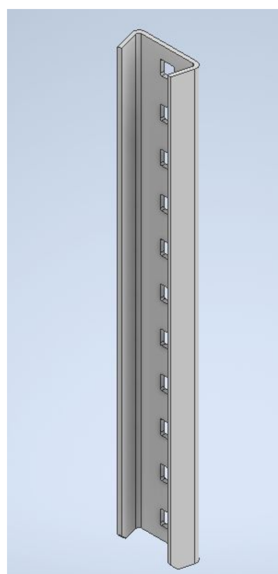


Figure 9
CAD model of the linear slide extension

Figure 10
Pictures of the sensors used on the robot

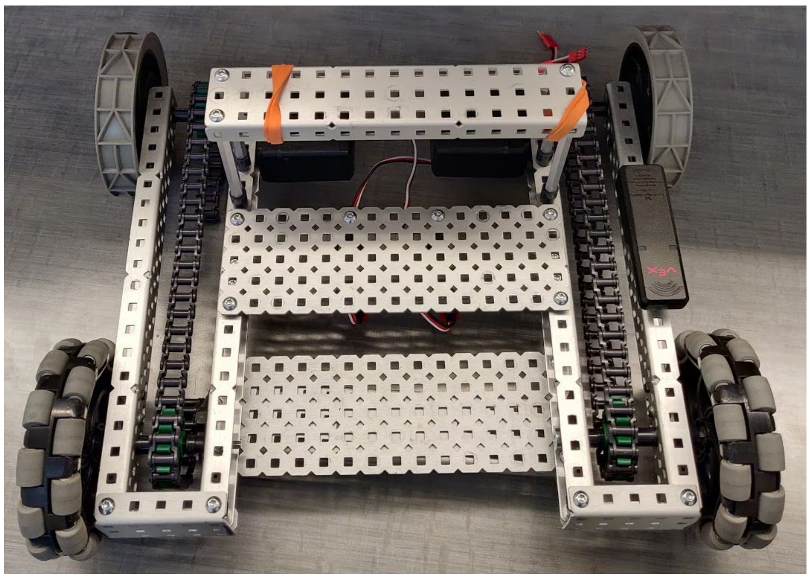


Figure 11
Picture of the drivetrain of the robot

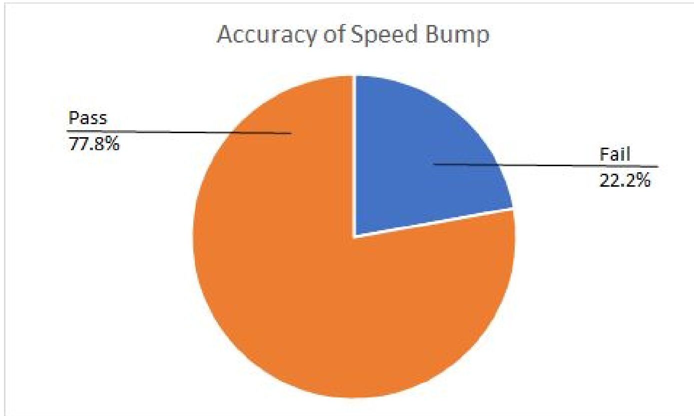


Figure 12
Graph depicting the pass/fail results of the traveling over the speed bump

Construction Zone Entry			
	low	med	high
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
pass	in zone with pizza within 15 sec		
fail	drop pizza		
time fail	more 15 sec	avg 3 seconds	

Figure 13
Test results of the robot traveling over the speed bump. This test showed that the integrated system could only travel over the speed bump if it had the claw lowered down.

Figure 14

Test results of the robot picking up pizzas off the ground for the PDR. The test concluded that the 10:5 and the 10:10 were the only suitable options for picking up pizzas.

Figure 15:

Test results of the claw mechanism testing with the addition of plates. The test helped us to conclude that the addition of any plates helps but the larger the plates the more beneficial.

Figure 16:
Test results of the wheeled intake to decide how many rubber bands were needed in addition to the intake wheel for a more successful pick up. The conclusion was that 3 or 4 rubber bands would be best.

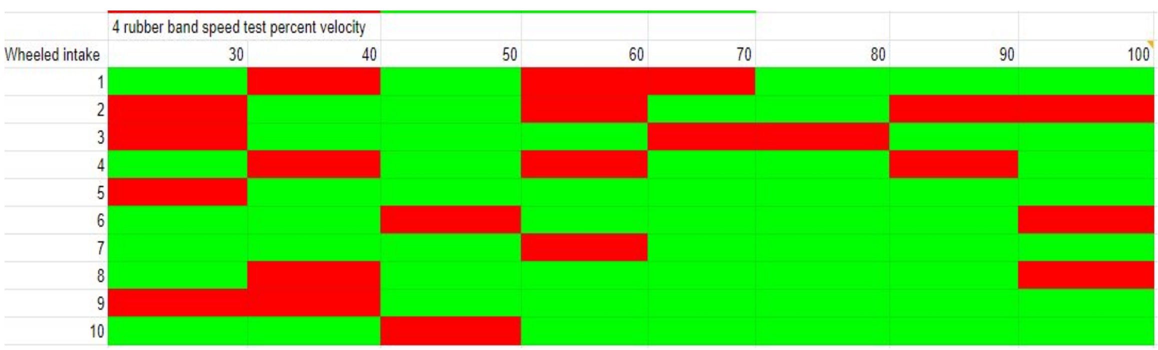


Figure 17:
The test to show how changes in the roller intake speed changed the accuracy of the pizza pickup. It was concluded that 70-80 percent was the best.

Figure 18:
The test was used to determine the reliability of our entire system to pick up a pizza, from getting it from the bakery delivering it to the height and not dropping it. The test showed us that we could reach almost all the levels.

Figure 19:
This test showed that our current system of aerial delivery would not work. Insted we removed it and used our claw and elevator system to raise instead.