

McGILL UNIVERSITY

ECSE 211: FINAL DESIGN PROJECT

Hardware Design Document

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1 Summary

1.1 Purpose of this document

This document presents the entire design process of the hardware division team. It contains all the designs used during the project. It explains why some were chosen instead of others, what issues we have encountered, and how we ended up with the final design of "iStallion".

1.2 How to read it

Images Most of the sections have also images in the appendices. When reading a section, look at the appendices at the end of the document for visual support.

Test Finally, some sections have reference to test results. Please refer to the testing document for further information. There, the test results and conclusions are described in details.

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2 Review of Lab 5 and new designs

We did a complete review of the 3 designs from Lab 5. The easiest design to create is the catapult. Therefore, every design without exception consisted of a catapult. However, we have come up with three new launching mechanism ideas (see also the drawings from week 1 and figures 1-3 in Appendix A):

- Crossbow: Using a large rubber band, we could build a crossbow structure.

Why we discarded it initially: The issue with this design is its complexity. Making a structure to accommodate rubber bands is tricky. To rewind the rubber band, we need a gear mechanism and another mechanism for the trigger. If we use only one brick, this means that we have only two motors to do everything.

- Catapult: Simplest design, and the more reliable. It consists of the catapult used in lab 5, but with a bigger height. The downside of this mechanism is that the ball has almost no speed in x. To gain enough speed, the catapult needs to be at more than 30 cm above the ground. This adds a lot of instability to the structure. The tower also adds a significant weight and stress on the chassis.

Why we chose it: This is one of the simplest designs. It has fewer moving parts and needs only one motor to activate. This leaves one port free for a reloading mechanism.

- Double motor catapult: Same as the catapult, but with second motor at the end to provide more torque.

Why we discarded it: Making a structure to support the torsion created by two motors is extremely complex. The force added from the second motor would likely destroy the tower.

3 Presentation of the creation process

3.1 Spiral process

To create our robot, we used an iterative process best represented by a spiral: as soon as a mechanism is created, it is tested. This way, each module (launcher, chassis, defence mechanism...) is tested thoroughly before we add it to the main prototype.

3.2 Modular design

This also explains why we chose a modular design for the robot. Task separation is easier. As an example, Philippe worked on the chassis while Romain worked on the crossbow design. Each was able to perform individual tests on their design and make changes accordingly. At the end, they assembled the two modules like Meccano model and tested the prototype as a whole.

3.3 Pictures

We tried to take as many pictures as possible, even though we were continuously changing parts. Every picture was put in the appendices for this document. Additional information was added in caption.

3.4 LDD Files

To allow recreation of every step of the process, we created an Lego Digital Design file for each Mark. We also supplied LDD files for the funnel reservoir, the piston launcher and the wheel launcher.

3.5 Construction reports

Finally, to illustrate the iterative process, we added construction reports in Appendix for the reloading and ball collecting of Mark IV

3.6 Videos

For testing, adding to the testing document and the appendices, we have filmed certain tests (launching mechanism, localization) to further document the process.

4 Mark I

This is the first prototype built. It was presented to Prof. Lowther on the 08/03/2017. It has several features:

- Catapult (attack mechanism): The firing mechanism is a long single-motor catapult. The extremely long arm is long enough to give the ball a high speed, but short enough so the torque of the motor can move it easily. To get the maximum speed out of the motor, we used an unregulated class. As an input, we can only use milliseconds (i.e. no degrees).
- The wheelbase is large to accommodate the brick and prevent the robot from turning over. However, because of this feature, we must pay attention to the weight distribution: if too much weight is put on the wheels, the axles will bend.
- 2 metal balls in the back to support most of the weight of the robot.
- 2 bricks: Allows for more sensors and motors. The software team has not decided if we will keep two bricks or just one. The difficulty of using two bricks is the communication between them. If the bluetooth does work properly, we will have communication issues between the two bricks and the whole system will not work.
- Strong triangular structure with cross members to support the strength of the arm.
- Primitive ball collecting system: On the side of the robot, we made a rail by connecting black rods. When a ball is dropped, the rail collects them. The first ball in the queue sits above a medium motor connected to an "L" shaped bracket. When the catapult is ready for reloading, the motor turns 90° and slowly pushes the ball in the catapult cup.
- Cardboard wall (defence mechanism): We want to keep the defence mechanism as simple as possible. For that reason, we don't want to use motors or any mechanical device. Keeping this in mind, we took a big piece of cardboard from a recycling bin and stuck it directly on the side of the robot. It will fully cover the target and we don't need a complex mechanism to lift it.

Note. See "Mark I.lxf"

5 Mark II (February 26 to March 8)

5.1 Changes and testing for the first time

At first, we felt the robot was too unstable to add height to the tower. Therefore, we changed the back of the robot from one ball to two on each side. However, we then noticed something off: the axle was bending and the wheels were not straight. This was due to the change in the weight distribution. Nevertheless, we decided to keep the two balls, but moved them right below the motors for the wheel.

After solving the instability, we added a superstructure which moved up the catapult by 20 cm. The structure was extremely solid and stable. It was perfect to support the torque of the catapult.

During testing, we increased the arm of the catapult by 5 cm to test if the ball launch would be more powerful. However, we realized that beyond a certain length (approximately 50 cm), the motor was not powerful enough to lift it. After that test 5a-5b (under Test Documents), we decided to keep the length at about 35 cm.

Next we tested the distance covered by the Mark II launch mechanism. Keeping in mind its enormous dimensions, we postulate it would be at least 9 tiles. From test 5a-5b, we discovered it was in fact close to 11 tiles.

However, we noticed that the connection points from the chassis to the tower were not enough: the tower ended up moving from side to side. For the connection points, we used "H" shaped pieces. These pieces did not connect tight enough, partially explaining why the tower was moving so much.

5.2 The downside of using large structure

Due to the superstructure's height and weight, it added tremendous stress on the main chassis. Because we only use two connection points, the tower was moving when firing. We decided to investigate two options:

- We can change the firing mechanism. The catapult needs a lot of potential energy for long distance firing. Rubber bands, for example, can deliver a great deal of power faster.
- We can change the main chassis, while keeping the tower and the catapult. It is the easiest solution, which enables us to keep a mechanism that was tested and works.

Note. See "Mark II.lxf"

6 From Mark II to Mark III: testing of new launch mechanism (March 8 to March 17)

6.1 Presentation of the spinning wheels mechanism

We decided to first consider other launch mechanism that were not in the initial brainstorming. The main design that we came up with was the spinning wheels. It consists of two wheels each linked to a gear mechanism connected to large EV3 motors. Because of the gear ratio of 6 to 1 (2 set of big and small gears connected together), the wheel would spin a lot faster than the motor, at the expense of torque.

This mechanism allows the ball to get a great amount of speed in a short amount of time.

6.2 Testing results and problems encountered

The build of this system was relatively quick. We set the acceleration of the motor to be slow, to prevent the gears from grinding.

Our first test was simply to push the ball between the wheels. The result was not acceptable: the ball went for about 2 tiles with a medium speed and almost no height. The contact between the wheels and the ball were very short, so the ball couldn't be triggered at its maximum potential.

We tried 2 solutions to correct this problem. First, we implemented another set of gears in the transmission to increase the speed. This moved the ratio up by a factor of 1.5 (9 to 1). We then realized the torque was too much for the motor to handle. The gears were not moving and when they did, they were rubbing together.

We then tried another approach: keep 2 sets of gears, but put more wheels and link them with rubber bands. This way, the ball will be in contact with the spinning structures for at least 10 cm.

In theory the idea looked great. But in practice, this created a lot of problems. The motors had difficulties spinning. The rubber bands kept slipping off the wheels.

6.3 Why we discarded this system

At the end of the test, we discarded the entire system. It was considered too unreliable, difficult to maintain and not powerful enough.

6.4 Crossbow

6.4.1 Advantages of rubber bands and crossbow

Like we said earlier, rubber bands can deliver a lot of power in a short amount of time. However, they need a strong mechanism to stretch them and release them quickly.

The crossbow is a really flexible design. We can easily adjust the angle of launching. Because the chassis is modular, we will always be able to go back to a catapult design if something goes wrong.

6.4.2 Construction of the system

We started the construction of the crossbow by creating a large frame capable of sustaining the enormous tension of the rubber band. To hold the ball, we first created a platform sliding on two rails. While testing, we saw there was too much friction because of the rails.

We changed the rails for a direct contact with the ball, so no energy was lost to friction. By trial and error, we found the optimal position for the rubber band, which was around the middle of the ball. Too high or too low and the ball would sliding off.

We build a ratchet system to prevent the rubber band from unwinding. A piece connected to the axle could turned clockwise given that a 4-hole piece prevented it from turning counter-clockwise.

A winding mechanism was also improve to put tension on the rubber bands. It consisted of a small piece of string attached to a rotating shaft. While testing, we noticed that during the release, the rubber band was forced to move the string and the shaft. This created an enormous amount of energy that was lost.

To prevent this from happening, we needed to somehow to unwind the string from the shaft, while keeping the rubber band in this stretch position. In the first place, we added a trigger to immobilize it. Then, we put the motor in reverse to free the shaft.

6.4.3 Prototype of March 21, 2017

For the demo, we are using the crossbow design. The reloading mechanism is partially done: there is no system to move the ball to the firing chamber. The trigger is automated with a large EV3 motor. Like before, a ratchet mechanism allows it to go only in one direction. However, the winding of the rubber band still needs to be done manually.

To summarize, the main issue (trigger mechanism) was solved for the demo on Friday. However, the automated systems (reloading, moving the ball from the dispenser...) are not completed. They will be the focus of next week hardware design.

For more details on March 24 demo, please refer to the testing document.

7 Mark III: Downsize robot with crossbow (March 17 to March 24)

For the third version of the robot, we built an extremely solid base. Numerous cross members linked the two drive trains. Four pillars supports the tower. We squeezed the chassis in every direction to simulate extreme operating conditions and it barely disrupted the structure. The stability is less important because there is no tower to get the crossbow higher.

The firing mechanism of Mark III is the crossbow. This is a huge shift from all our previous designs. Like mention in the previous section, only the basic functionalities worked.

Note. For the LDD file, please refer to the final version as the only difference is the reloading.

8 Mark IV: Final design before the competition (March 24 to March 29)

This robot is the continuation of Mark III, with now a fully functional reloading mechanism. This robot is using the crossbow mechanism with two motors: one for reloading and trigger and another for pulling the rubber band.

8.1 Reloading mechanism

See construction reports in Appendix B. Strings are used to adjust the angle of the reloading mechanism.

8.2 Ball collecting mechanism

See construction reports in Appendix B

8.3 Weight distribution

MOTOR WEIGHT To put more weight on the front wheels, we added two large motors.

8.4 Defence mechanism

8.4.1 Option 1: Cardboard

A rectangular piece of cardboard is placed on the side of the robot. The robot will position itself right in front of the target, at the starting point of the green zone.

8.4.2 Option 2: Plastic bag

A plastic bag is placed on the side of the robot and stretched with metal rods. It will be connected to the reloading system, so it can fold and easily allow corner localization.

8.4.3 Our choice

We will use the plastic bag because of its small weight, can absorb the shock of the ball and can fold with the reloading mechanism, therefore taking less space.

APPENDICES

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APPENDIX A: Hardware pictures

Previous design

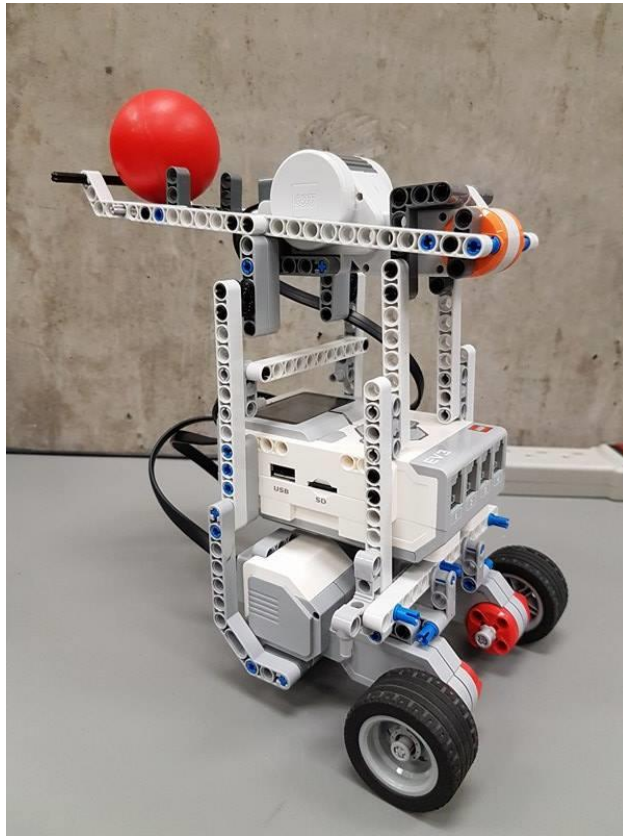


Figure 1

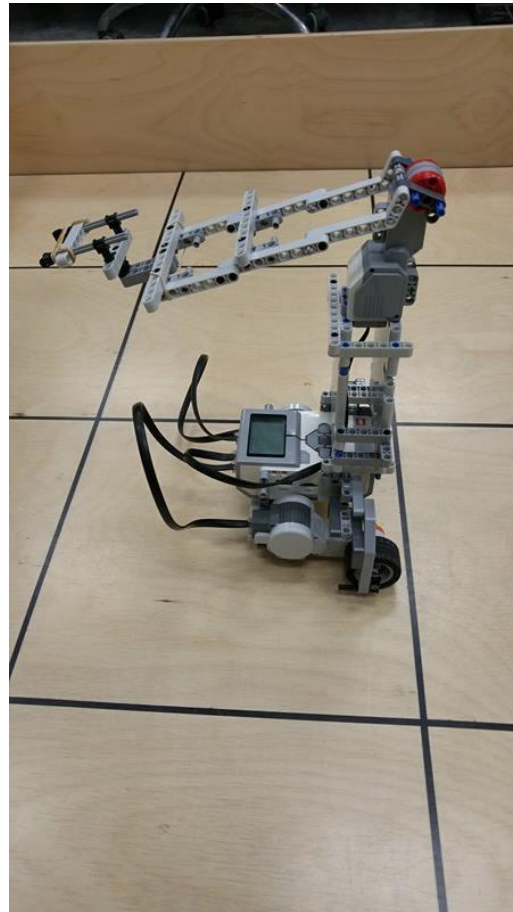


Figure 2

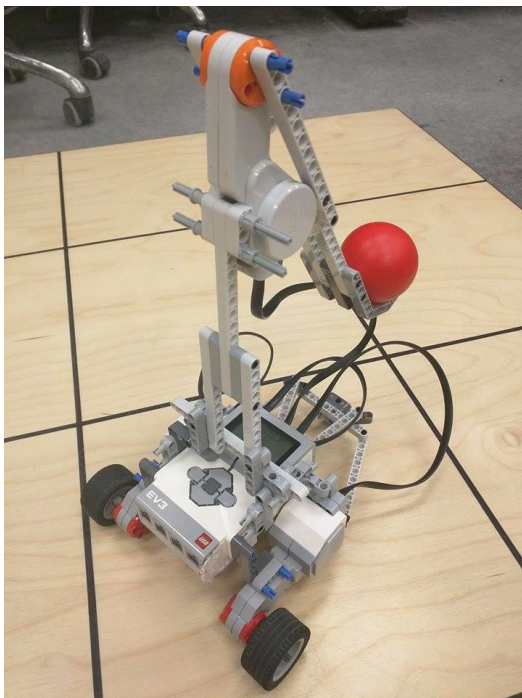


Figure 3

Figure 1, 2 and 3: These are the designs used by the individual teams for Lab 5. All used a catapult design because of its simple mechanism. We used the robot of figure 3 as a start for Mark I. We built the tower on top of it, and gradually disassembled the other two for the parts.

Mark I

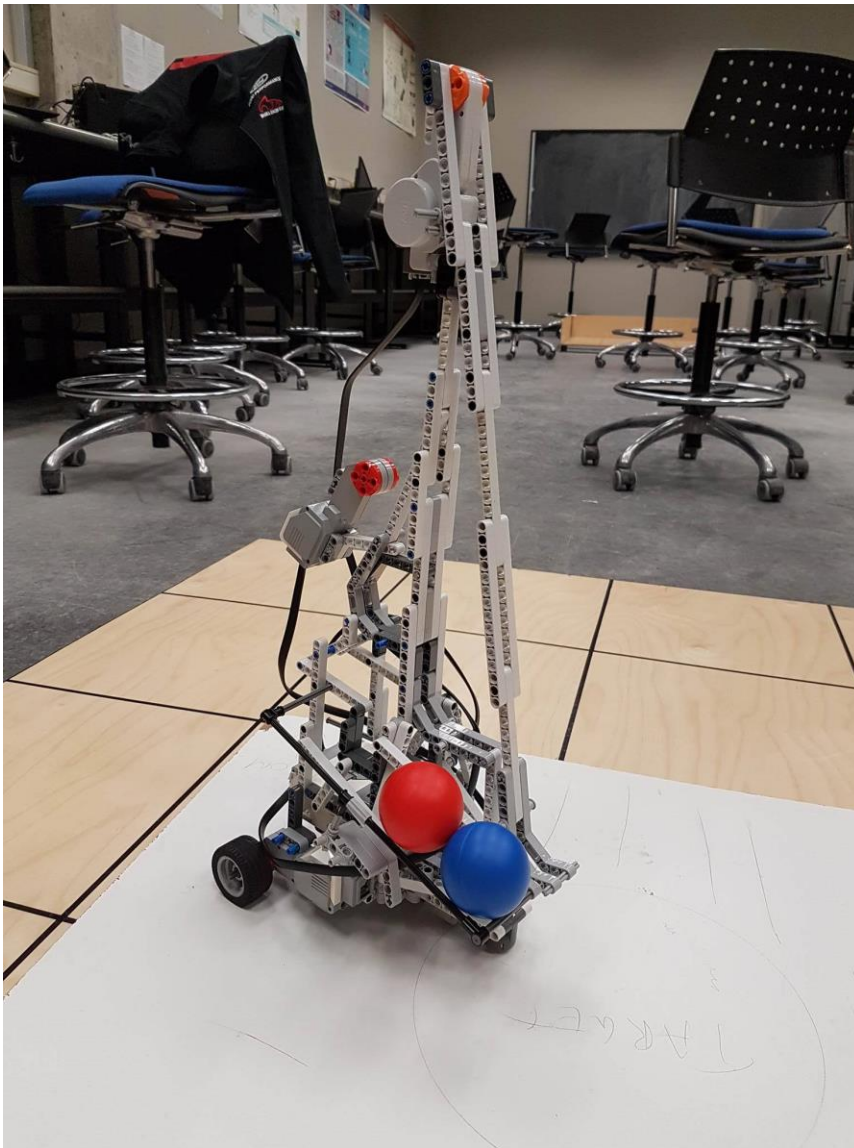


Figure 4

Figure 4: This is the first design of the robot. The massive catapault arm takes most of the space, and at that time there was no second brick in the back. When shooting, the robot moved slightly forward and the arm flexed.

The robot also had a mediocre ball collecting system composed of rail on the left side. Under the blue ball, there was a medium motor connected to an "L" shaped piece. When rotating 90°, it pushed the first ball in the catapault cup. The second ball would go down, but was stopped from falling by the motor

We intended to use the central motor for the defense mechanism. It was dropped in the later version.

Note: the tower of the catapault has no cross member and is only composed of a center piece.

Mark II

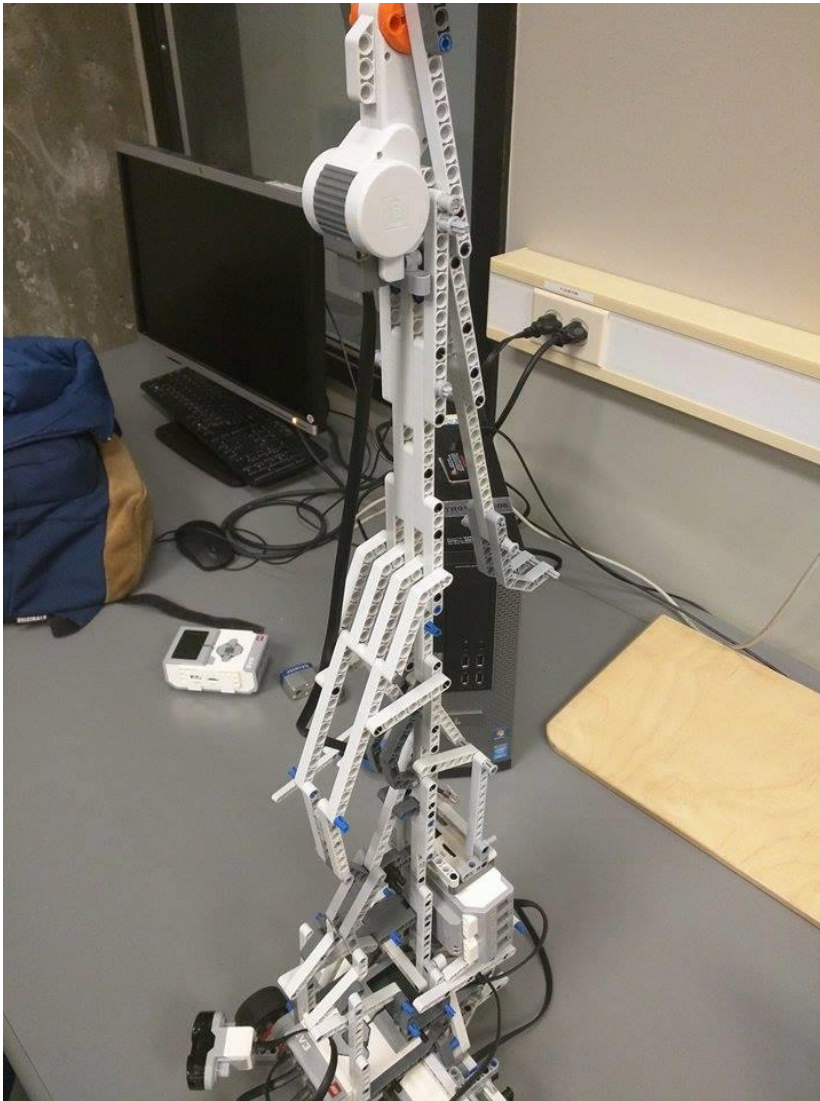


Figure 5

Figure 5: This is the main view of Mark II, which was a big step forward. The tower was enormous: at least 25 cm higher than Mark I. To support all this weight, we added numerous cross members and 45° pieces.

The second brick was added on the small flat piece in the back of Mark I. The arm was smaller compared to Mark I, which posed numerous problems with the reloading mechanism. Since at that time we didn't have the specs of the dispenser, we decided to concentrate on other issues.

Piston mechanism

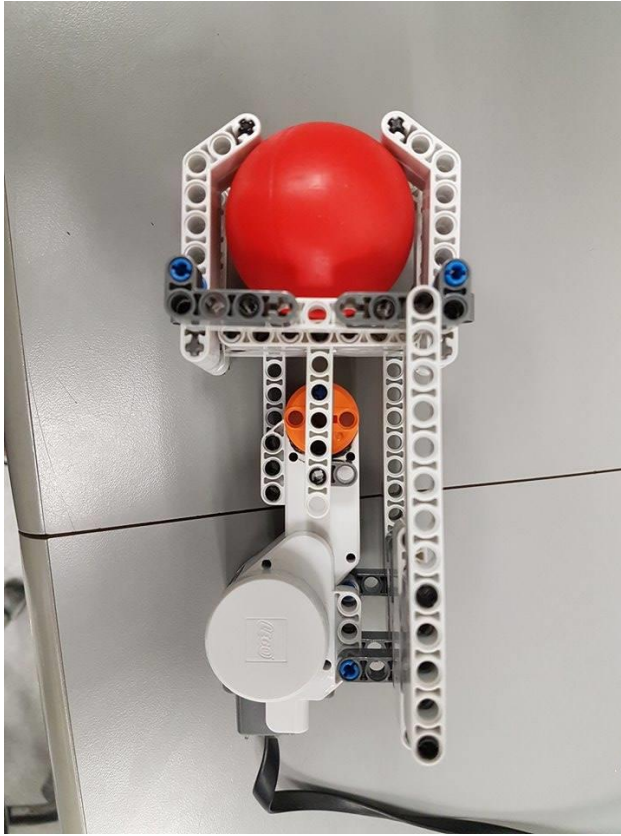


Figure 6

Figure 6 and 7: A piston mechanism prototype designed in parallel with the catapult launcher. The large motor created a crankshaft mechanism. The flat surface pushed the ball between the two 45° pieces. These pieces flexed and eventually pushed the ball out of the chamber.

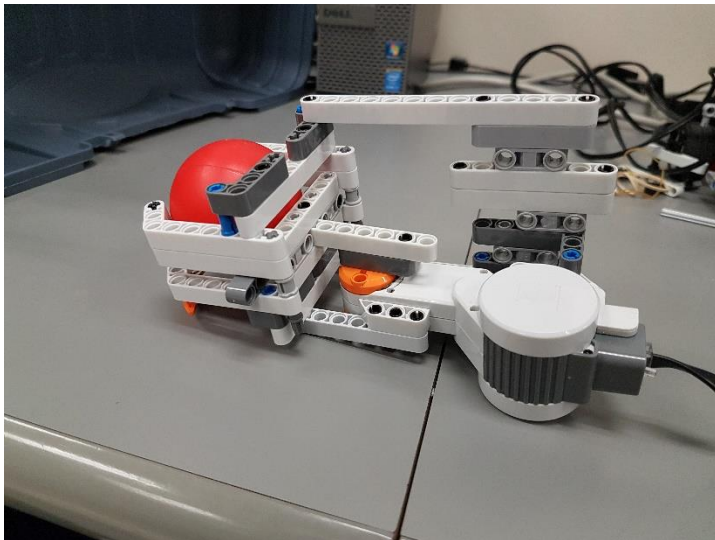


Figure 7

New Launcher designs

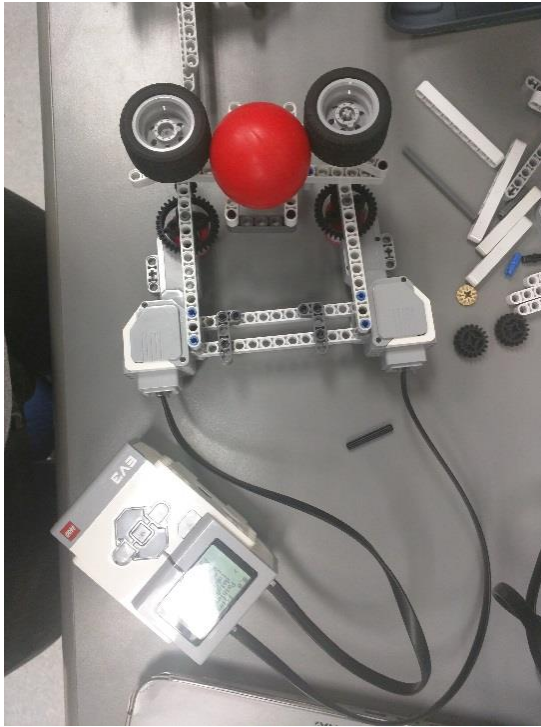


Figure 8

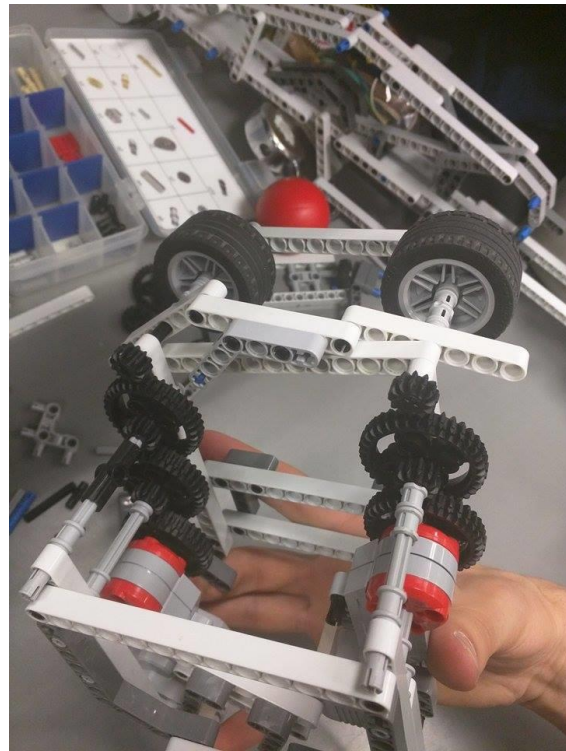


Figure 9

Figure 8 and 9: After trying the catapult, we wanted to know if we could build a better mechanism. First, we revisited an old mechanism from lab 5: the spinning wheels. We needed to adjust perfectly the distance between the wheels, so the ball could slide just the right amount, while not getting stuck. The structuring below the wheels needed to be rigid to keep the wheel distance constant. In Figure 9, we see the gear mechanism used to greatly increase the speed at the expense of the torque.

Demo prototype main view

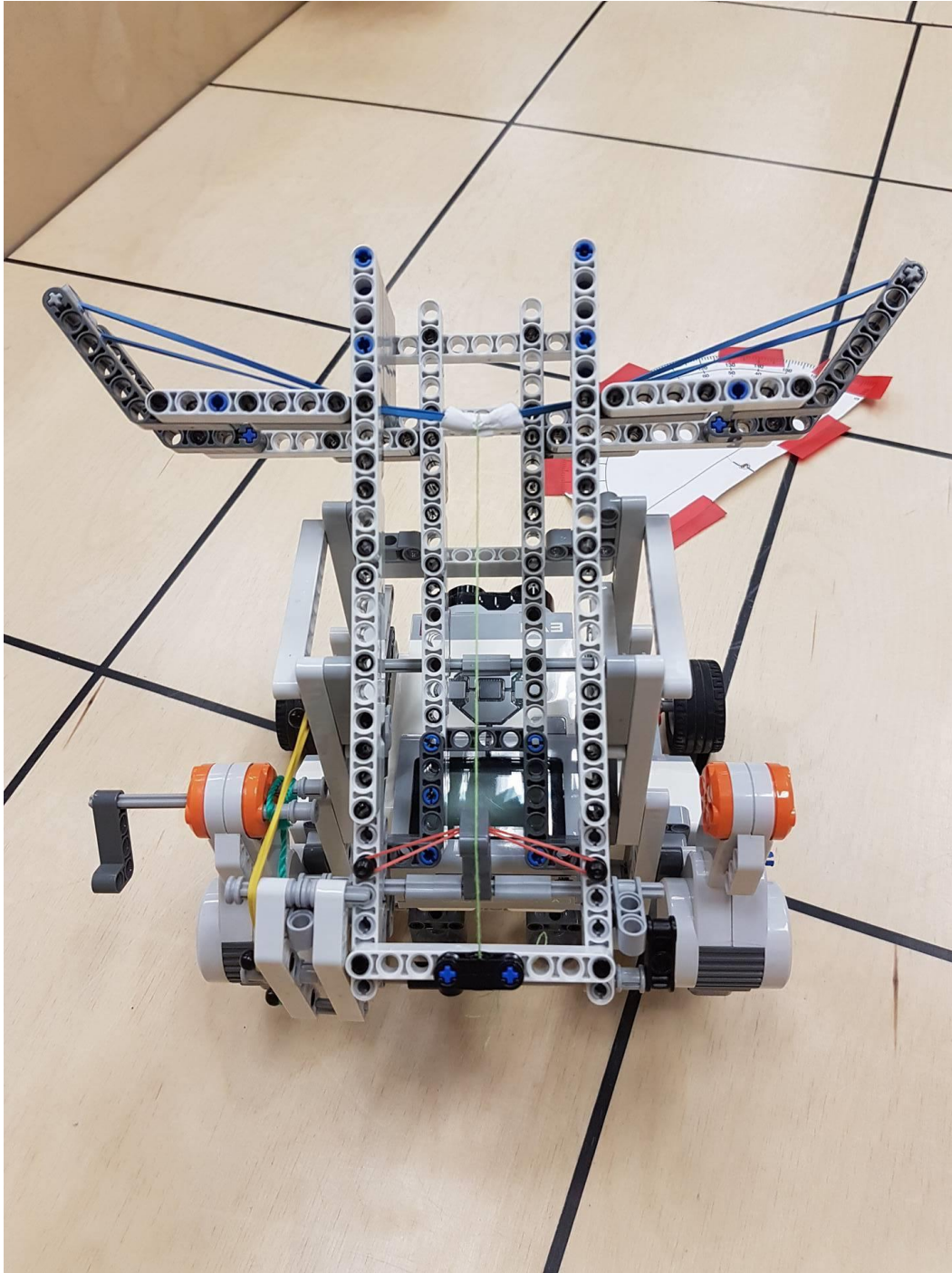


Figure 10

Figure 10: This is a top view of the crossbow prototype for the demo on 24/03/2017. From this point of view, you can easily see the main features: lighter string for reloading, paper to distribute the weight on the blue rubber band, trigger on the left. The trigger is still not connected to the right motor.

Prototype's chassis structure

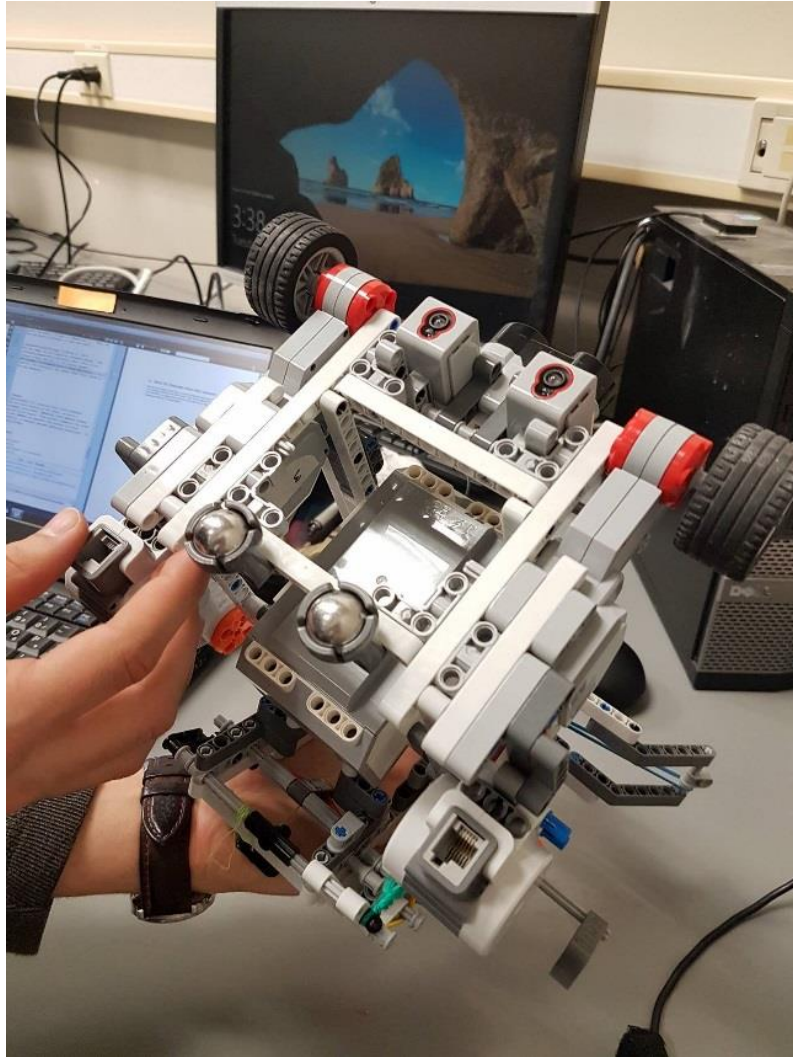


Figure 11

Figure 11: This is a bottom view of the chassis. The main beams are sandwiched between cross pieces (center of the chassis) and the motors. A piece runs in the middle connection of the motor to connect with the main beam through an “H” shaped piece.

Different views of the prototype

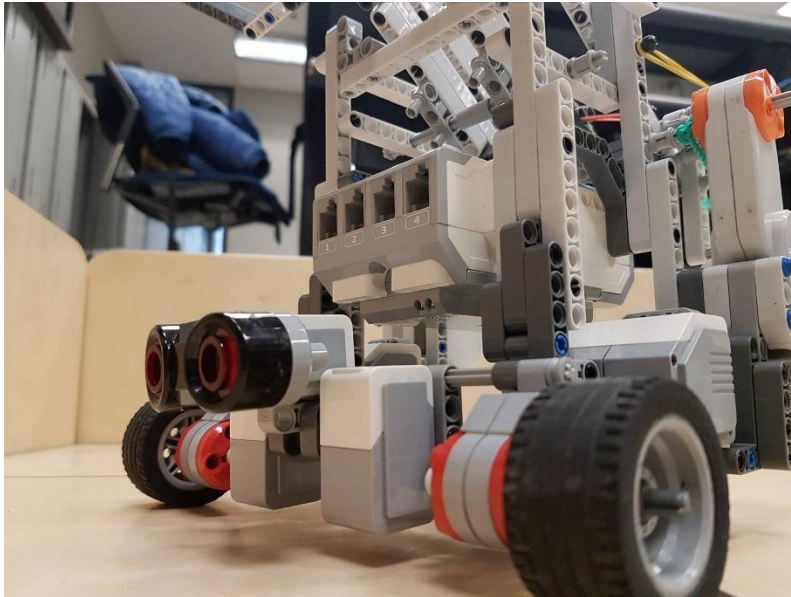


Figure 12

Figures 12, 13 and 14: Different views of the demo prototype. The crossbow allows the user to change the angle of inclination, which affects the x and y speed of the ball.

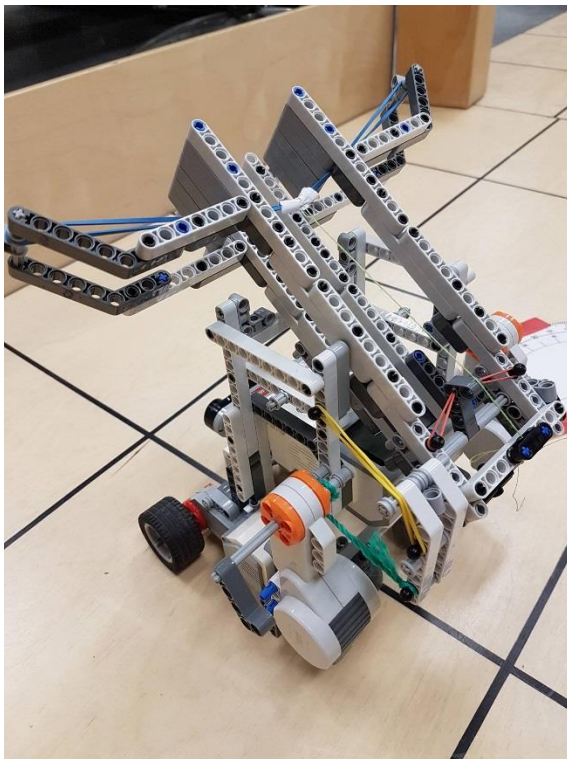


Figure 13

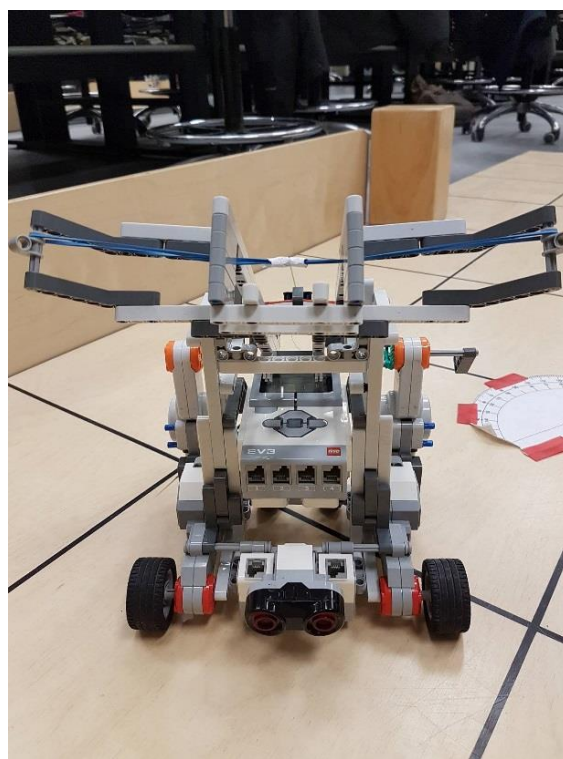


Figure 14

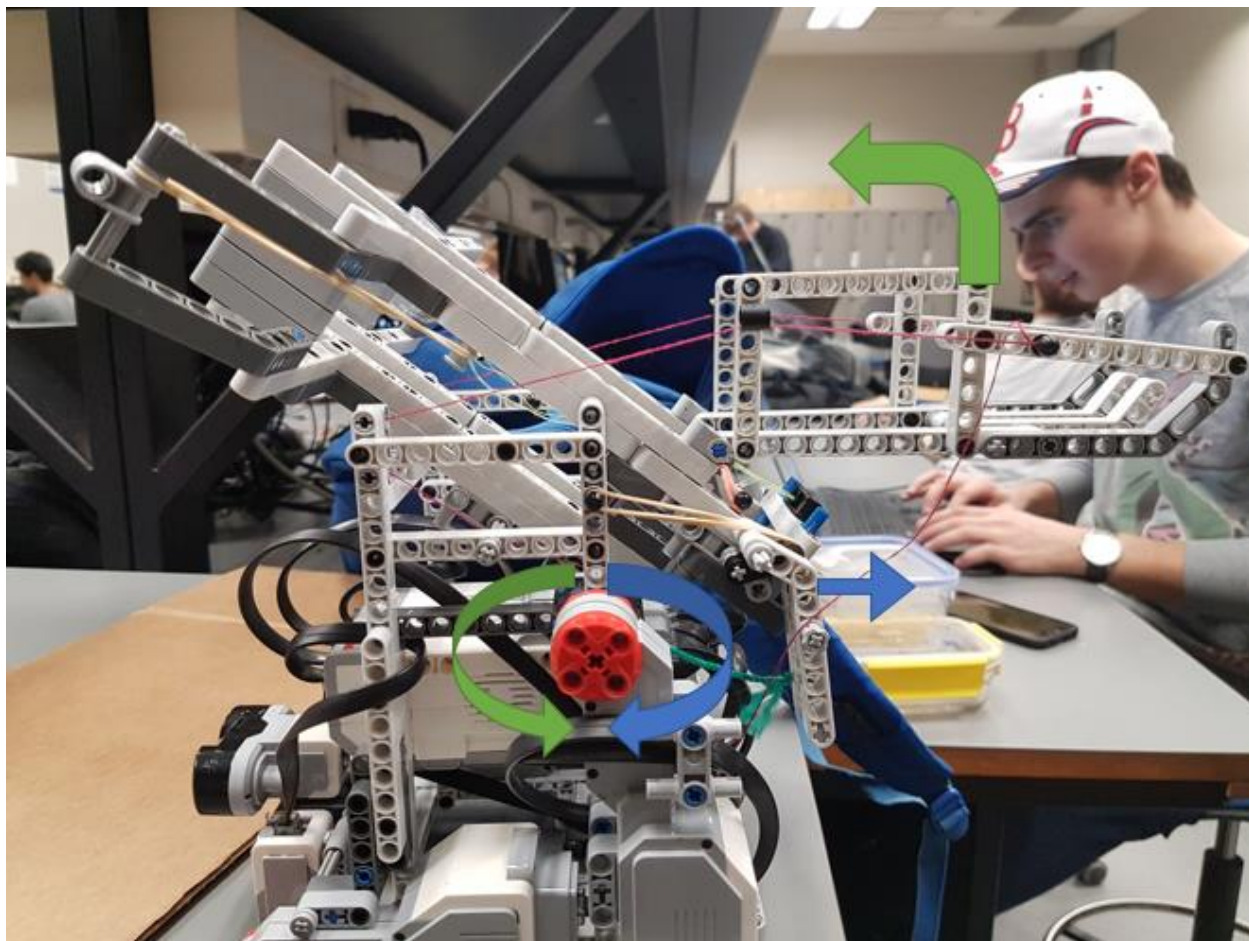


Figure 15

Figure 15: Trigger mechanism (blue arrow) actioned by clockwise rotation of the motor and ball loading (green arrow) by a counter clockwise rotation.

Defense mechanism



Figure 16: We attached a plastic bag to the main frame of the robot and the reloading mechanism. The plastic bag covers a great area, but folds if necessary to allow corner localization.

Figure 16

APPENDIX B

Construction Reports

Ball Reloading and Reservoir Mechanism

Done by Romain Nith on the 27/03/17 – Corrected by Nayem (04/04/17)

Problem: To reduce the distance traveled by the robot, we need to design a reservoir to store the balls retrieved at the ball dispenser. The reservoir will store and reload the crossbow at the same time.

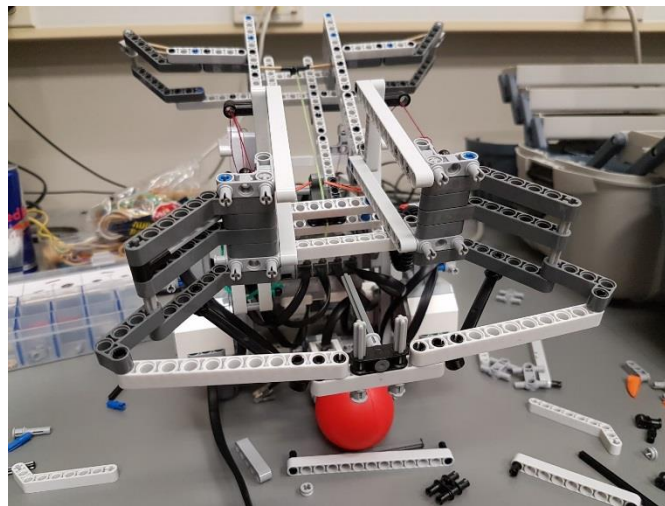
Version 1

By traveling, the robot is prone to errors and is not expected to arrive at the ball dispenser perfectly. To prevent the robot from not being able to retrieve any ball, the reservoir would look like a funnel feeding the ball into a rail that leads directly to the firing chamber.

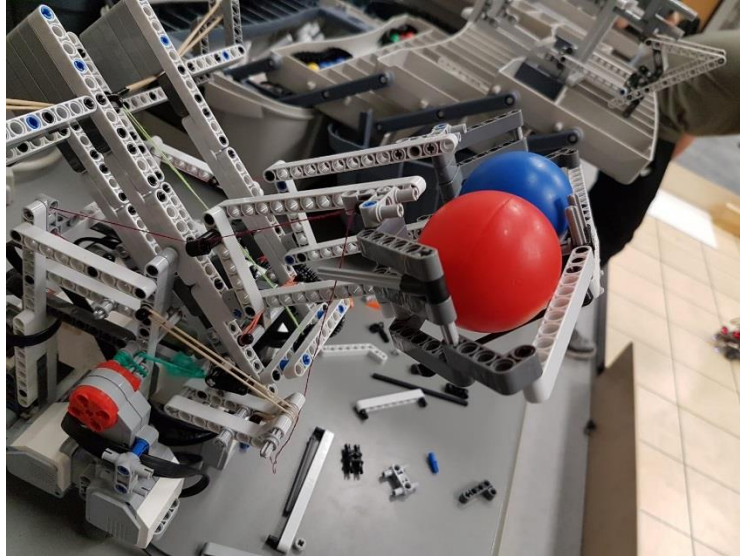
To pull up the entire system, a pulley mechanism with a string is being used. The string will be winded by the same motor used to pull on the crossbow trigger. It has been designed to not pull on the trigger when a ball is being dropped to the chamber: rotating clockwise will lift the reservoir and counter clockwise will pull on the trigger while lifting slightly but not enough to roll a ball into the chamber.

Iteration 1:

The reservoir's floor is being made with Lego blocks

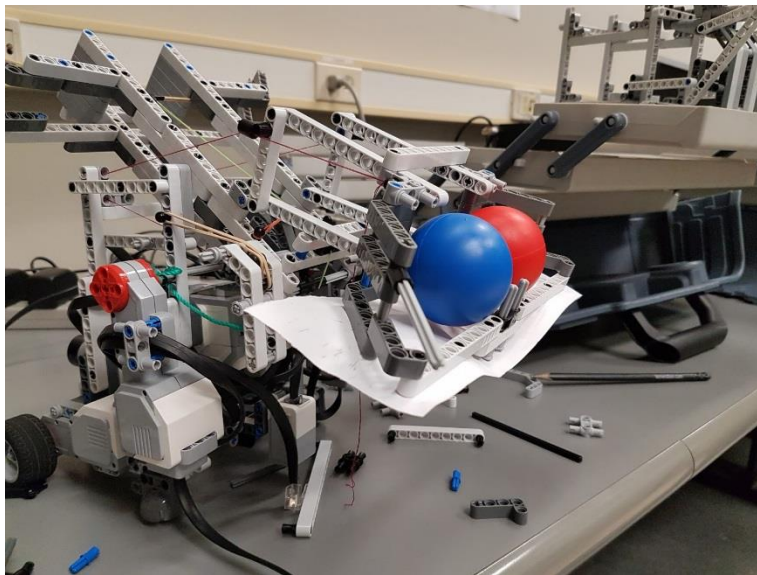


Issue: the reservoir is too large and balls would get stuck

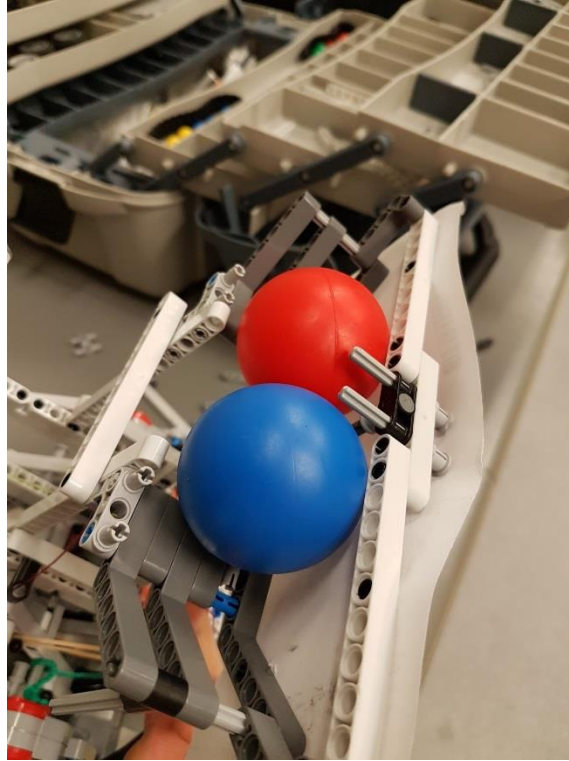


Iteration 2:

Change the reservoir to lift the height of the floor so the balls would fall into the rails more easily. Floor is being made out of paper.



Issue: reservoir still too large and balls would get stuck



Iteration 3:

Reduce the extension of the funnel's exterior arms

Issue: reservoir still too large and balls would get stuck

Version 2

Assume the robot arrives at the dispenser with only plus or minus 2cm of error. Instead of a funnel, the robot would only have a large rail so the balls just stay aligned and are directly in the main rail ready to be dropped into the firing chamber.

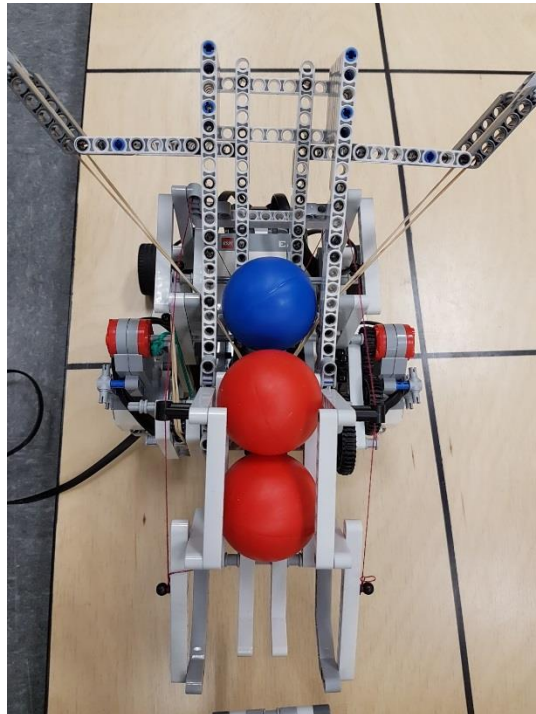
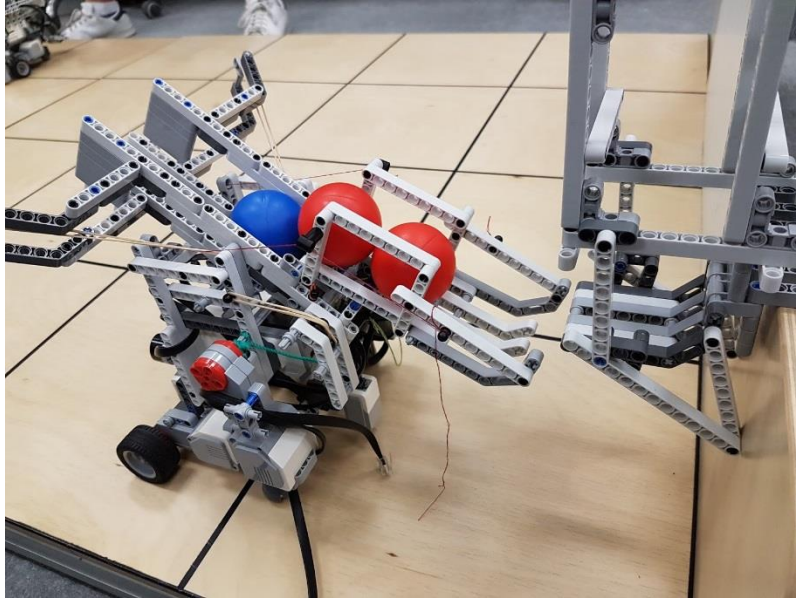
Iteration 1:

Using the same rail of the previous version.

Issue: the opening isn't wide enough and the robot has to be precisely under the dispenser to retrieve the ball

Iteration 2:

Shortening the upper rail for a wider opening.



Result

The system works with [2.8; 3.3] cm of errors according to Dispenser Test document.