HARDWARE DESIGN DOCUMENT

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Original Author: Alex Hale

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[22/10/2017] Alex Hale: created document and added preliminary information
[23/10/2017] Frederic Cyr: filled in the features and pros/cons for the three alternatives.
[28/10/2017] Frederic Cyr: updated the pictures with proper backgrounds.
[30/10/2017] Frederic Cyr: added all the information for section 7.0 (Chosen Mechanical Design)
[30/10/2017] Alex Hale: grammatical and formatting changes.
[4/10/2017] Frederic Cyr: added the features, and pros & cons for second chosen mechanical design.
[5/11/2017] Alex Hale: added R&D Lab 5 robot description; improved referencing of models from testing document; grammatical and formatting changes
[6/10/2017] Frederic Cyr: added free-body diagram of draft #2 and a small description.
[14/10/2017] Frederic Cyr: added the last modifications to the final design (section 9)
[15/10/2017] Frederic Cyr: added the LDD sketch and final physical representation of the robot.
[19/11/2017] Alex Hale: minor edits to final section of document

1.0 - TABLE OF CONTENTS

9.2 LDD final design

2.0 - MOTORS
The large NXT motors are older than the EV3 ones, but aside from a difference in attachment points, they are identical.

The main difference between the large and medium motors is power and precision. The large motors are more powerful, but less accurate, while the medium motor is less powerful, but more precise. The large motors will be used for jobs like driving the robot around, while the medium motor will be used for jobs like moving a sensor back and forth. All motors connect to ports A through D on the top of the brick.

3.0 - BRICK
The brick has four ports for motors (A through D) and four ports for sensors (1 through 4).

4.0 - SENSORS
The gyroscopic sensor allows you to measure the angle and angular velocity of the robot. It is not used often, but may be useful for this year's project. All sensors connect to the ports labelled 1 through 4 on the bottom of the brick.

The light (colour) sensor can determine the colour of an object, the intensity of the light reflected by an object, or the ambient light level. To detect the black lines on the game floor, the intensity of reflected light will be used. Determining the colour of an object will be useful for identifying the opponent's flag during the competition.

The ultrasonic sensor is used to measure distance by sending ultrasonic waves and measuring how long it takes the wave to echo back. Its main use is in detecting obstacles the robot needs to avoid.

5.0 - RESEARCH AND DEVELOPMENT LABORATORY ROBOT
The first tests were carried out with the robot from Laboratory #5, so it is important to document the features of that robot here. This robot is also relevant because most of its design requirements were the same as those of the final project robot, meaning most of the final project robot's design elements were sourced from this robot.

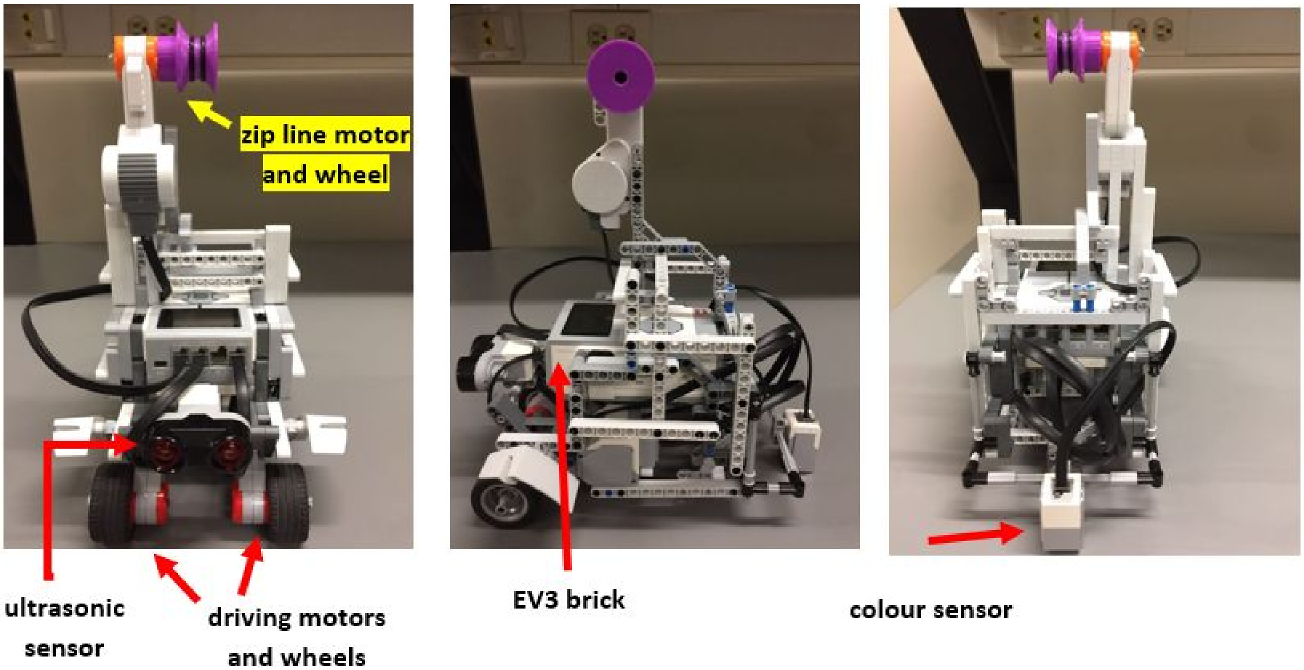


Figure 5.1 - Laboratory 5 Robot Design
(from left to right: front, side, and rear)

The robot features three motors, two wheels, one zip line wheel, one ball bearing, one ultrasonic sensor, one colour sensor, one EV3 brick, and various connecting pieces. The ultrasonic sensor is mounted to the front of the robot, at the same height as the brick, while the colour sensor is mounted to the rear of the robot, just behind the ball bearing.

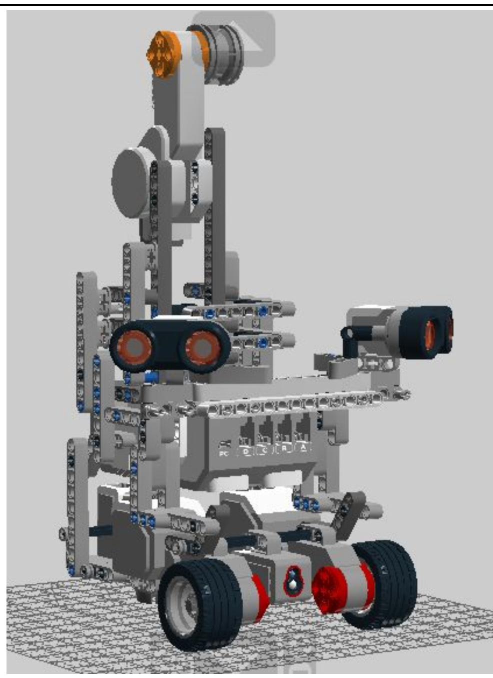
6.0 - DEVELOPMENT HARDWARE DESIGNS

6.1 - Option 1

- Set two ultrasonic sensors at 45 degrees in front of the robot.
- Set one light sensor in front of the robot, between the two ultrasonic sensors, facing straight ahead.
- Set the other light sensor as close as possible to the floor on the back of the robot, pointing downward for localization.
- Set the EV3 brick horizontally (important for the balance point).
- Set the wheels slightly larger than the width of the EV3 brick, with two motors.

PROs	CONs
Can detect a good range of distances since	No remaining ports for gyro sensor.

the two ultrasonic sensors are both oriented at a 45 degree angle.	
Only three motors, the weight is well-distributed.	Might fail to detect an obstacle at 180 degrees
The two light sensors are set pretty low.	The two ultrasonic sensors might be set too high and give incorrect readings. All the sensors are fixed.



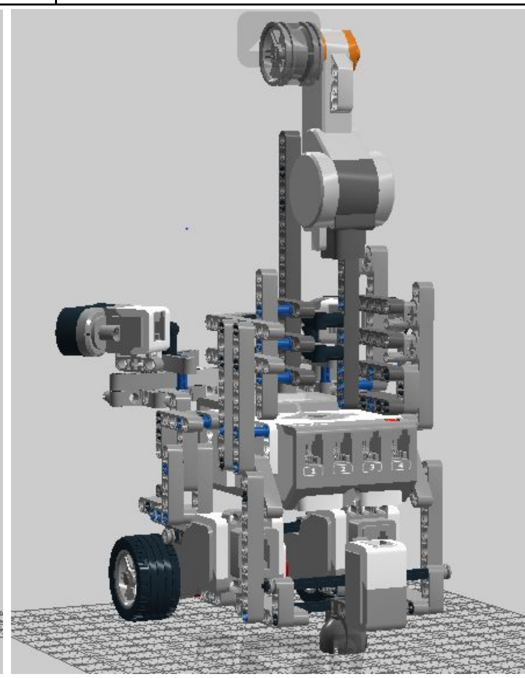


Figure 6.1.1 Option #1 - Front view

Figure 6.1.2 Option #1 - Rear view

6.2 - Option 2

- Set one ultrasonic sensor and one light sensors that are pivoting together in front of the robot. Use one medium motor.
- Set one fixed light sensor as close as possible to the floor on the back of the robot, pointing downward for localization.
- Set the EV3 block horizontally toward the front of the robot to avoid wheel slippage. As a result, we will need to add more weight toward the back for equilibrium. Thus, this robot will be heavier than the others.

PROs	CONs
The smallest robot, lower chance to hit obstacles during navigation or localization.	Height is too low.

The lightest robot, less supporting pressure on both motors.	Supporting arm needs revision .
Light and US sensors attached together, more efficient in detecting obstacles and targets.	

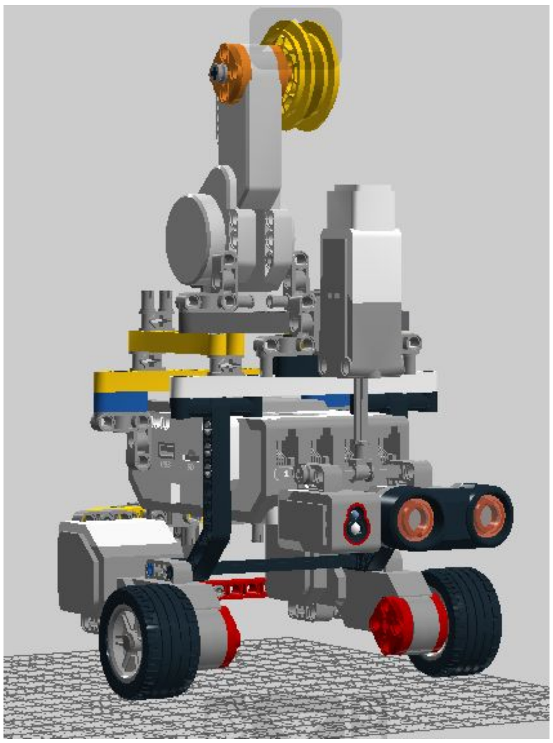


Figure 6.2.1 Option #2 - Front view

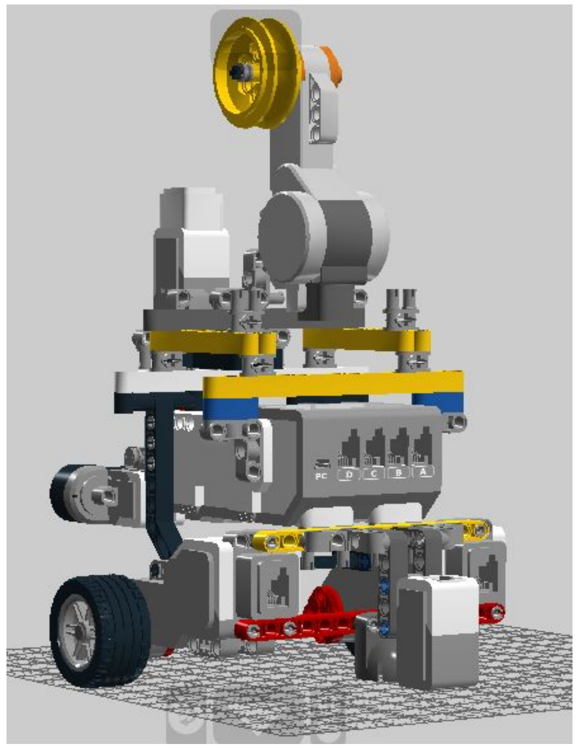


Figure 6.2.1 Option #2 - Rear view

6.3 - Option 3

- Set only one ultrasonic sensor in front of the robot that is pivoting. We will have to use one medium motor.
- Set one fixed light sensor in front of the robot that is facing straight ahead.
- Set one light sensor as close as possible to the floor on the back of the robot, pointing downward for localization.

PROs	CONs
Both the ultrasonic and light sensors positioned in front are low enough.	The stability of the arm should be revised.
The ultrasonic sensor can be moved.	The light sensor is not attached to the ultrasonic sensor, so it can't pivot and is

	less efficient for detecting the object's color.
Simple design, leaves one spare port for the gyro sensor if necessary.	

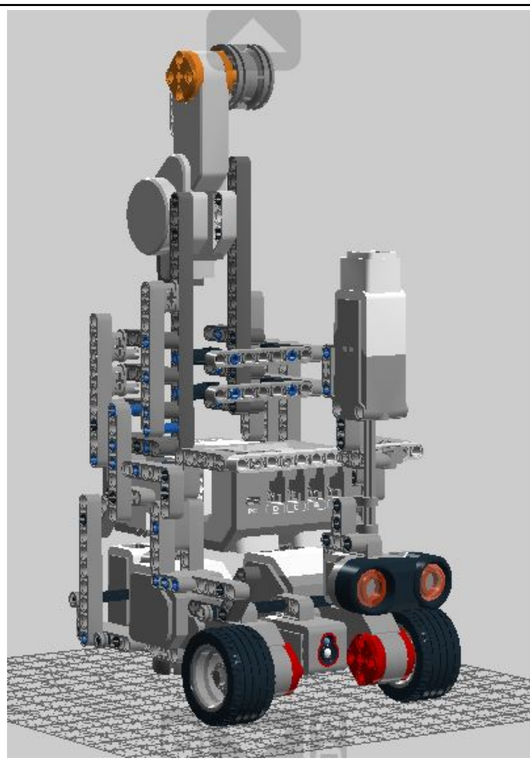


Figure 6.3.1 Option #3 - Front view

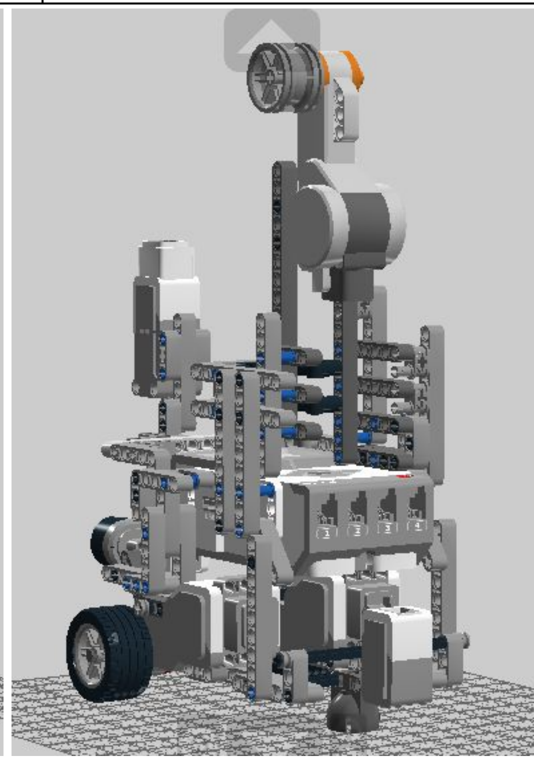


Figure 6.3.2 Option #3 - Rear view

7.0 - FIRST CHOSEN MECHANICAL DESIGN (DRAFT #1)

7.1 - Features

With the goal of building the robot in the most efficient and simplest way, we designed a robot capable of localizing its position everywhere on the 8x8 tile, avoiding and searching for obstacles and objects, and detecting the colours of blocks. Here are the physical characteristics of the chosen mechanical design:

- The wheels are placed 15.2 cm apart. This gives the robot stability and the ability to execute tight turns.
- A colour sensor is added in front of each wheel, pointing downward. The sensors are equidistant from the centre of the robot, simplifying the math required for localization.
- An ultrasonic sensor and a colour sensor are mounted to a medium motor. Both sensors are mounted low enough to detect any obstacles, and they can pivot at a 45^{o} angle either side of centre, allowing the use of P-Controller and Bang-Bang Controller. The

ultrasonic sensor is used to search for blocks and to avoid any obstacles placed on the grid, while the light sensor is used to detect the colours of blocks.

- The EV3 brick is positioned such that the wheels are weighed-down enough to avoid slippage. The brick is also placed such that it centres the balance point of the robot, crucial for crossing the zip line and navigating with precision.
- The robot is designed such that the battery can be accessed easily without damaging any components. This makes testing easier and allows for battery changes during the final competition.
- The pulley, placed on the right side of the robot, is tall enough to mount the zipline. The height of the zipline is 23.5 cm, and the pulley clears this height by approximately 2cm.
- The large NXT motor that powers the pulley wheel is also crucial in defining the robot's centre of gravity. The motor is positioned such that, when hanging from the zip line, the centre of gravity is at a point just beneath the EV3 brick's screen.
- To keep the design simple, as few supporting beams as possible are used. However, the stability of the robot is not compromised.

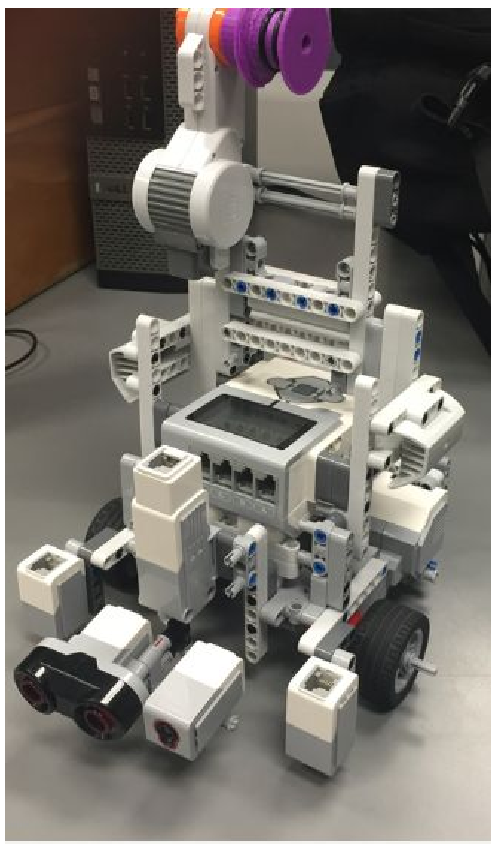


Figure 7.1.1 Physical representation of the chosen design (draft #1)

Dimensions:
Distance between the wheels: 15.2 cm
Height of the robot: 28.5 cm
Width of the robot: 19.8 cm
Depth of the robot: 21.2 cm

7.2 - Drawings

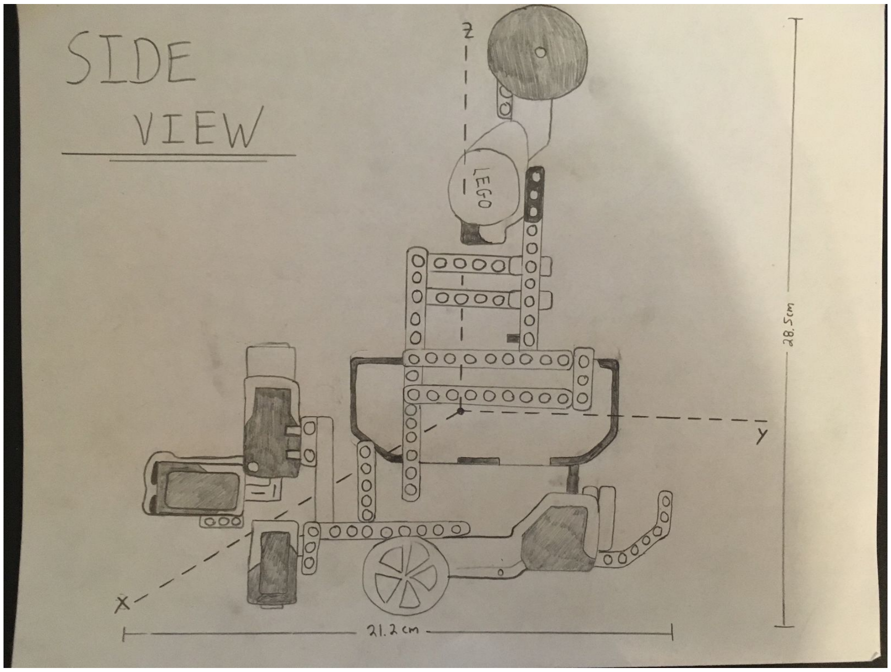
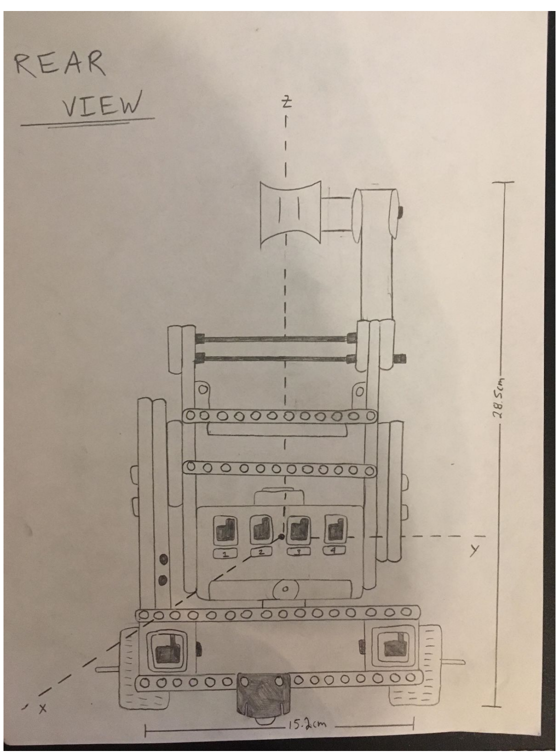


Figure 7.2.1 Sketch of the side view



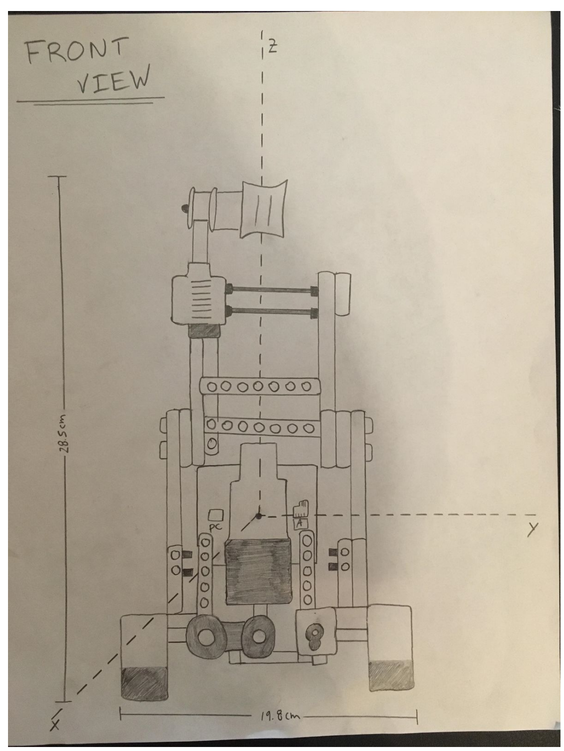


Figure 7.2.2 Sketch of the rear view　　*Figure 7.2.3 Sketch of the front view*

7.3 - Balance point

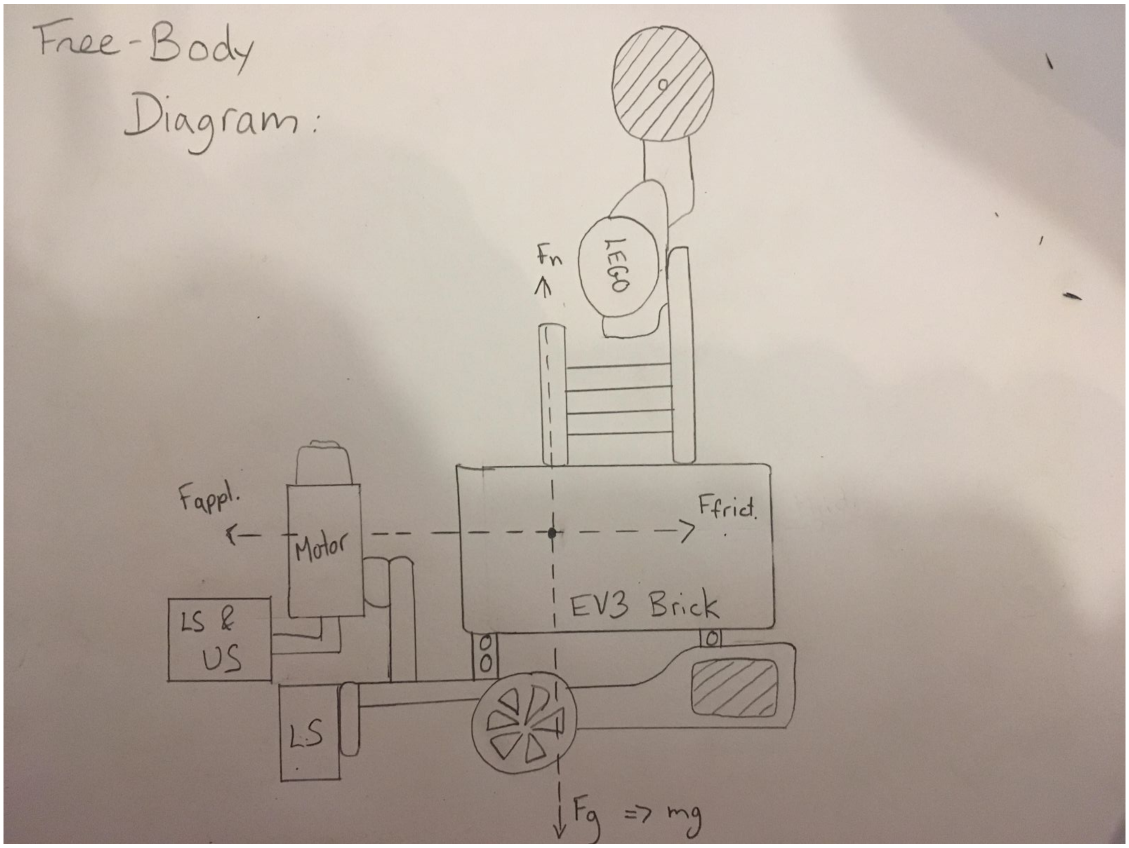


Figure 7.3.1 Simple representation of the free-body diagram (draft #1)

Throughout the building process, the centre of gravity was checked with experimentation. Testing the balance point on the zip line pointed us toward the approximate position of the centre of gravity. Some of our initial designs were unbalanced because the robot had more weight over the front, causing the robot to lean. To correct this problem, we moved the brick backward, but placed the NXT motor and pulley above the centre of the brick. As seen in Figure 6.3.1, the centre of gravity is at the lowest part of the brick's screen.

7.4 Pros and Cons

PROs	CONs
Both the ultrasonic and light sensors positioned in front are low enough.	No remaining ports for gyro sensor.

The ultrasonic and colour sensors can be moved.	The stability of the pivoting sensors should be revised.
Good accessibility to the battery.	
The width of the wheels make the robot stable but can also execute tight turns.	

7.5 - Evolution of design

The robot built for Laboratory #5 was a good representation of the final design, since the zip line was involved during the experiment. An additional light sensor was added in front of the robot in order to detect the colours of objects. After some experiments, we observed that a larger wheel axle will make the robot more stable, but too large will result in more complex turns. The position of EV3 brick was changed a few times to balance the amount of weight over the wheels with the centre of gravity. The most difficult task was to fix the NXT motor and pulley to the brick while maintaining the centre of gravity and balance point. The current mechanical design will be sent to the software team for initial testing, and revisions will be made if necessary.

8.0 - SECOND CHOSEN MECHANICAL DESIGN (DRAFT #2)

8.1 - Features

Some additions have been made to the first chosen mechanical design. For the purpose of better organization, this design will be labelled “Draft #2”, since major features are differ from the first chosen mechanical design - namely the robot’s base. Here is a list of changes made from the previous design:

- The base has been changed to be much simpler. The framework is lighter and more solid.
- The wheelbase has expanded to 15.23 cm.
- The downward-facing colour sensors have been moved toward the centre to improve light localization.
- The height of the pivoting sensors on the front of the robot has been increased to avoid picking up erroneous readings from the floor.
- The centre of gravity of the robot has been adjusted such that the robot leans slightly forward when traversing the zip line, ensuring the wheels can touch the floor and pull the robot away from the end of the zip line.
- The accessibility to the battery is improved.
- The structure of the zip line arm has been simplified.

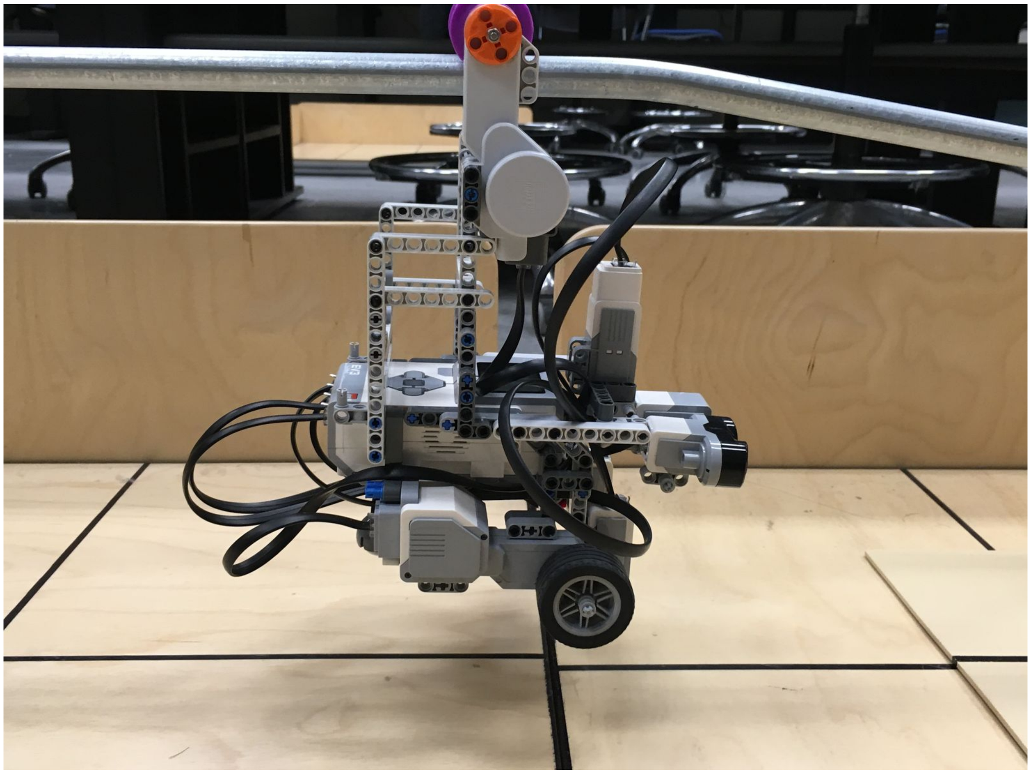


Figure 8.1.1 Physical representation of the chosen design (Draft #2)

<u>Dimensions:</u>
Distance between the wheels: 15.23 cm
Height of the robot: 26.8 cm
Width of the robot: 18.1 cm
Depth of the robot: 18.9 cm
Height of the rotating sensors: 7.0 cm
Distance between the two light sensors: 5.9 cm

8.2 - Balance point

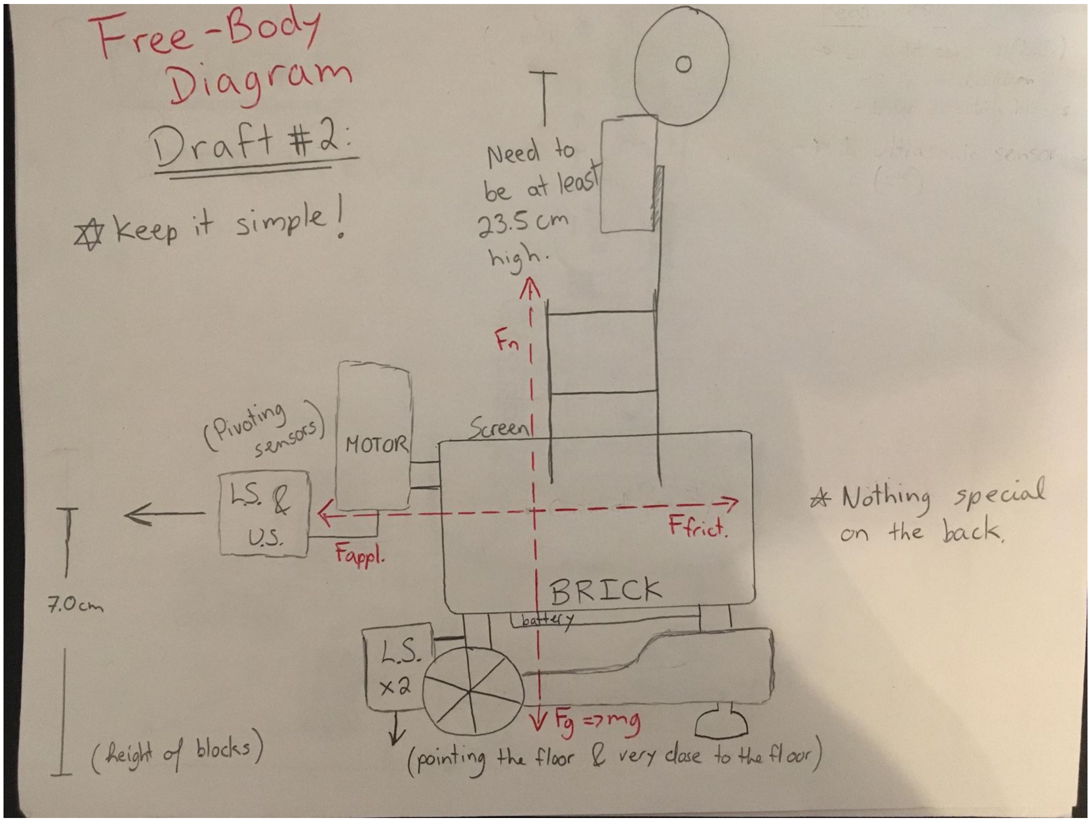


Figure 8.2.1 Simple representation of the free-body diagram (Draft #2)

When rebuilding the robot, the centre of gravity was again checked through experimentation. Testing the balance point on the zip line pointed us toward the approximate position of the centre of gravity, which is in nearly the same position as Draft #1 (located at the lowest part of the brick's screen). Again, the robot is leaning a little bit forward while traversing the zip line, but this makes the landing easier at the end of the zipline since the wheels touch the floor first.

8.3 - Pros and Cons

PROs	CONs
The pivoting ultrasonic and colour sensors are set high enough from the floor.	No remaining ports for gyro sensor.
The block-facing ultrasonic and colour sensors can be moved.	The stability of the pivoting sensors and the zip line arm could be improved.
Good accessibility to the battery (better	

than Draft #1).	
The width of the wheels makes the robot stable, but also allows for the execution of tight turns.	
The floor-facing colour sensors are closer to the floor than Draft #1, further improving light localization.	

9.0 - FINAL MECHANICAL DESIGN

9.1 - Final modifications

Prior to the beta demo, some changes were made to the second chosen mechanical design to increase the consistency of mounting the zipline. Two plastic funnels have been glued to the rotating purple wheel in order to enlarge the margin of error. WIth the modification, the funnel on the left side of the robot was coming into contact with a zip line support beam on approach. To fix this issue, the height of the robot was increased by 3 cm. The new zip line wheel gives the robot a new margin of error of 4.5^{o} to the right and 3.5^{o} to the left, as found in Test #24 of the testing document.

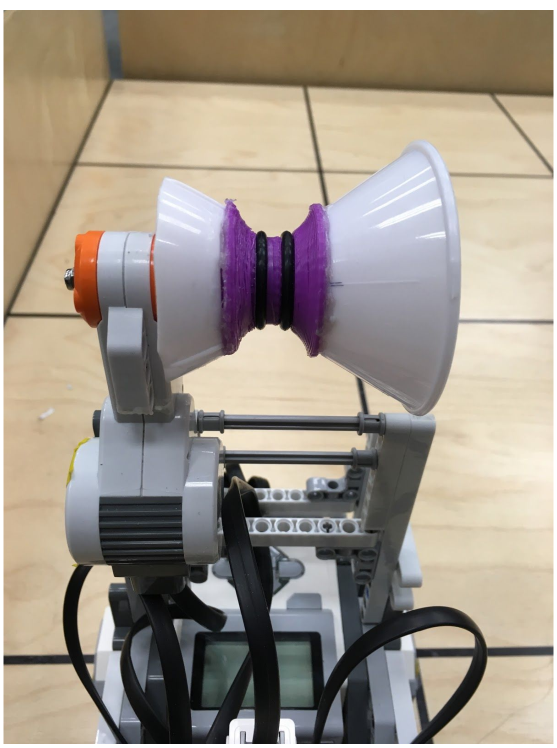


Figure 9.1.1 Two funnels extend the zipline wheel

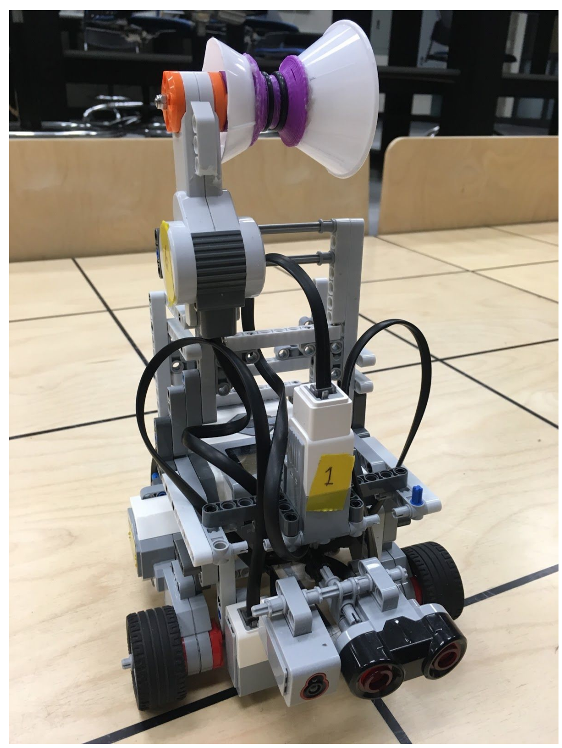


Figure 9.1.2 Final physical robot

9.2 - LDD of Final Design

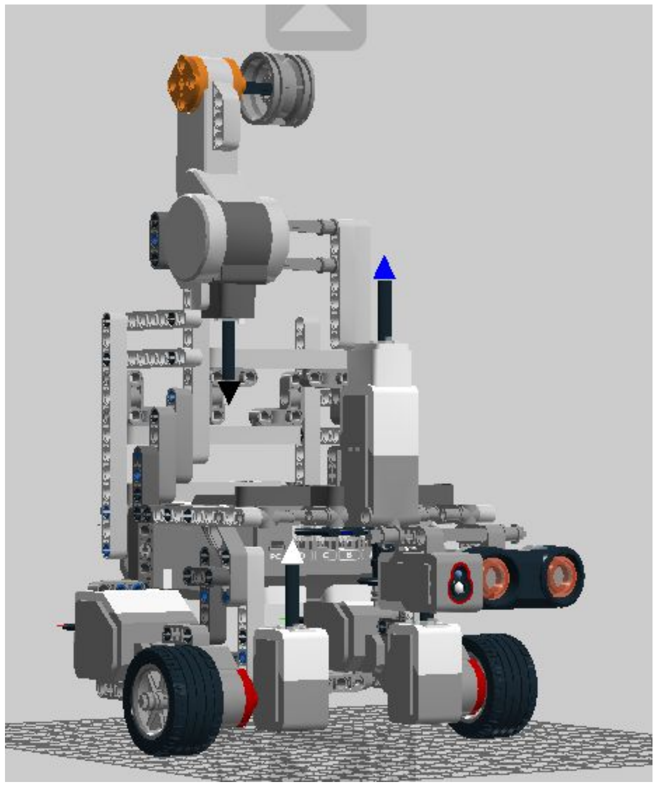


Figure 9.2.1 LDD representation of the final design