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ECSE 211: Design Principles & Methods
Lab 5: Ballistic Launcher

Section 1: Design Evaluation

Section 1.1 – Hardware Design

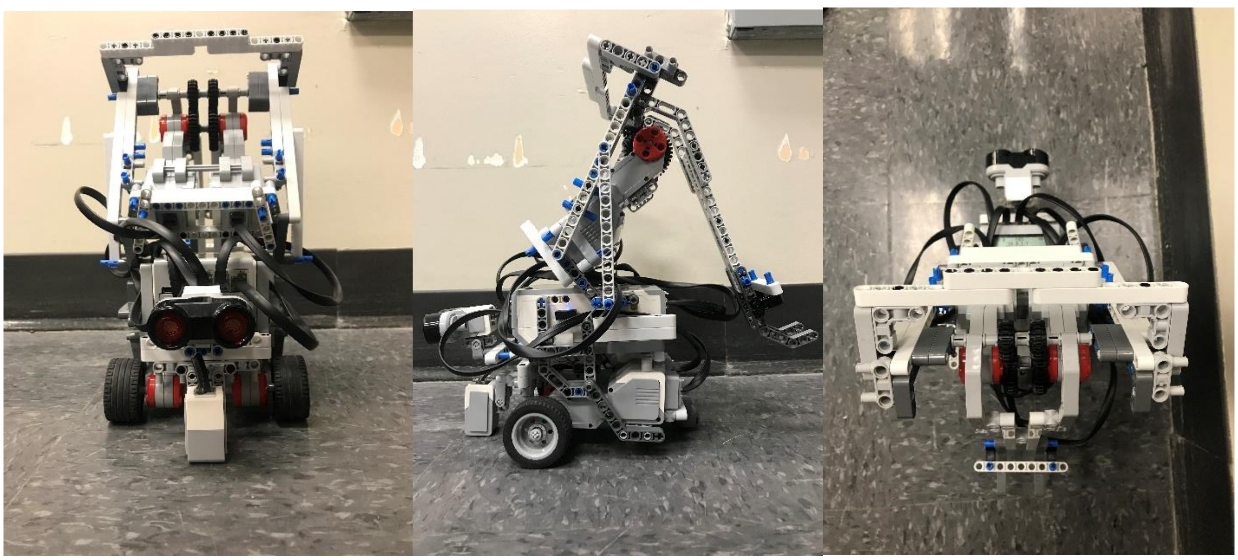

Figure 1: Front, side, and top views of the robot. The stopping bar can be seen at the top of the side photo, directly in the path of motion of the launcher. Each of the top mounted EV3 motors are mounted at 45 degrees and work in tandem to generate a more even distribution of torque and fire the ball the required distance.

The hardware design of our robot consists of 4 EV3 motors, the Ultrasonic (US) sensor, the light sensor, and an EV3 brick. Two of the motors are used for navigation for the robot, while the other two are used for powering the launcher.

The US sensor and light sensor are front mounted for ergonomic issues, namely to avoid the launcher, wheels, and the other parts of the chassis. The light sensor is mounted close to the ground to avoid detecting the shadow of the robot, as was often recorded when the robot was tested with the red mode sensor. The US sensor mounted front facing as the robot does not need to use obstacle detection as was the case in both lab 1 and 3.

The launcher motors run in parallel to generate a more consistent torque to the launcher. Each motor is attached to a large gear, which is used to spin two smaller gears to maximize the launcher velocity. The length of the launcher attachment is made such that the ball has time to generate the speed it needs to travel the required distance.

Finally, when the ball has reached its maximum velocity in the launcher, the base of the launcher (as seen nearest to the gears in fig. above) collides suddenly with a bar stopping the momentum of the launcher, sending the ball into flight thanks to conservation of momentum.

All these attributes of the launcher combine to allow the ball to be launched the required distance of 120cm.

Section 1.2 – Software Design

The software for this section can be separated into 5 distinct components: The US localizer, the light localizer, the odometer, the navigator, and the launcher. For the stationary launch, only the launcher is used while all the components are used for the mobile launch. Each component is described below in the order in which each section of the code activates:

Stationary Launch:

1. Launcher is called five times inside a for loop. The launcher launches a ball whenever the operator presses the center button.

Mobile Launch:

1. The Odometer thread is started.
2. The US localizer begins to run. The code for this localization is taken from lab 4, and an overview of the steps taken can be seen in fig. When the US localizer is finished running, the orientation of the robot is updated appropriately on the odometer. Ideally the robot should end up at a heading of 0°.
3. The light sensor localizer is also taken from the previous lab and is used to set the x and y value of the odometer to an accurate and representative value of the location of the robot. The robot then travels to (1, 1) and begins the navigation.
4. The navigation component is implemented in a similar manner to lab 4. If the minimum distance from the robot's starting position to the target coordinates is greater than 4.5 tile sizes (the minimum distance the robot must be away from the center of the target grid), the program calculates the angle at which the robot the robot must turn to travel to the target point and travels a distance 4.5 tile sizes less than the calculated minimum distance. If the minimum distance to the center of the target tile is less than 4.5 tiles sizes, the robot turns right 90°, travels to the end of the board, turns left 90° and recalculates the minimum distance, which now should be greater than 4.5 tile sizes.
5. After the completion of the navigation, the robot buzzes loudly and stops to wait for user input. Then, as in the stationary launch, pressing the center button releases the

launching mechanism up to 5 times.

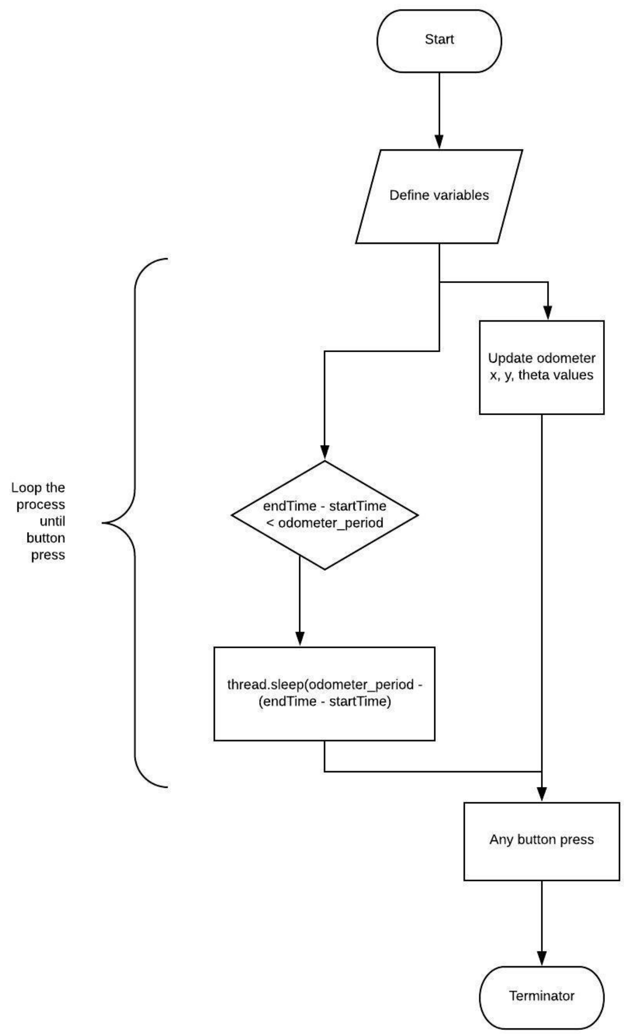

Figure 2: The software flow chart of the odometer class

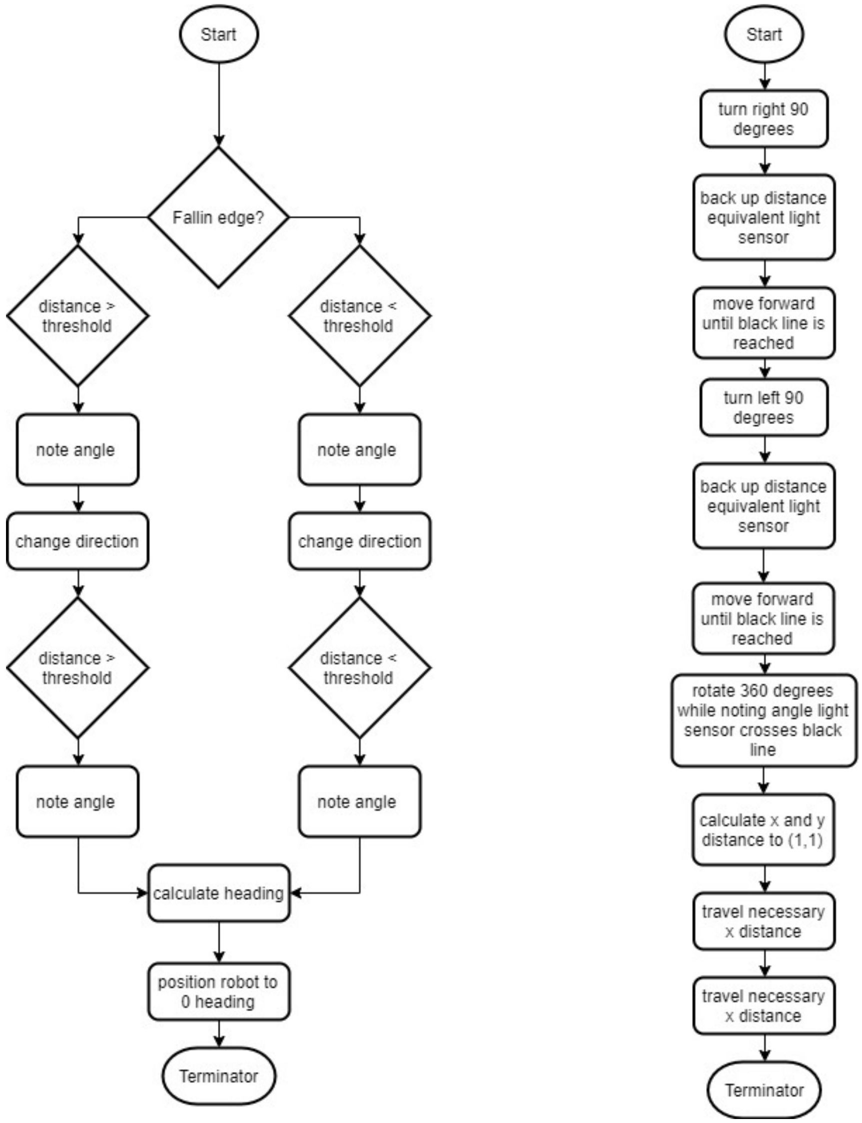

Figure 3: Flowchart for the USLocalizer and LSLocalizer classes

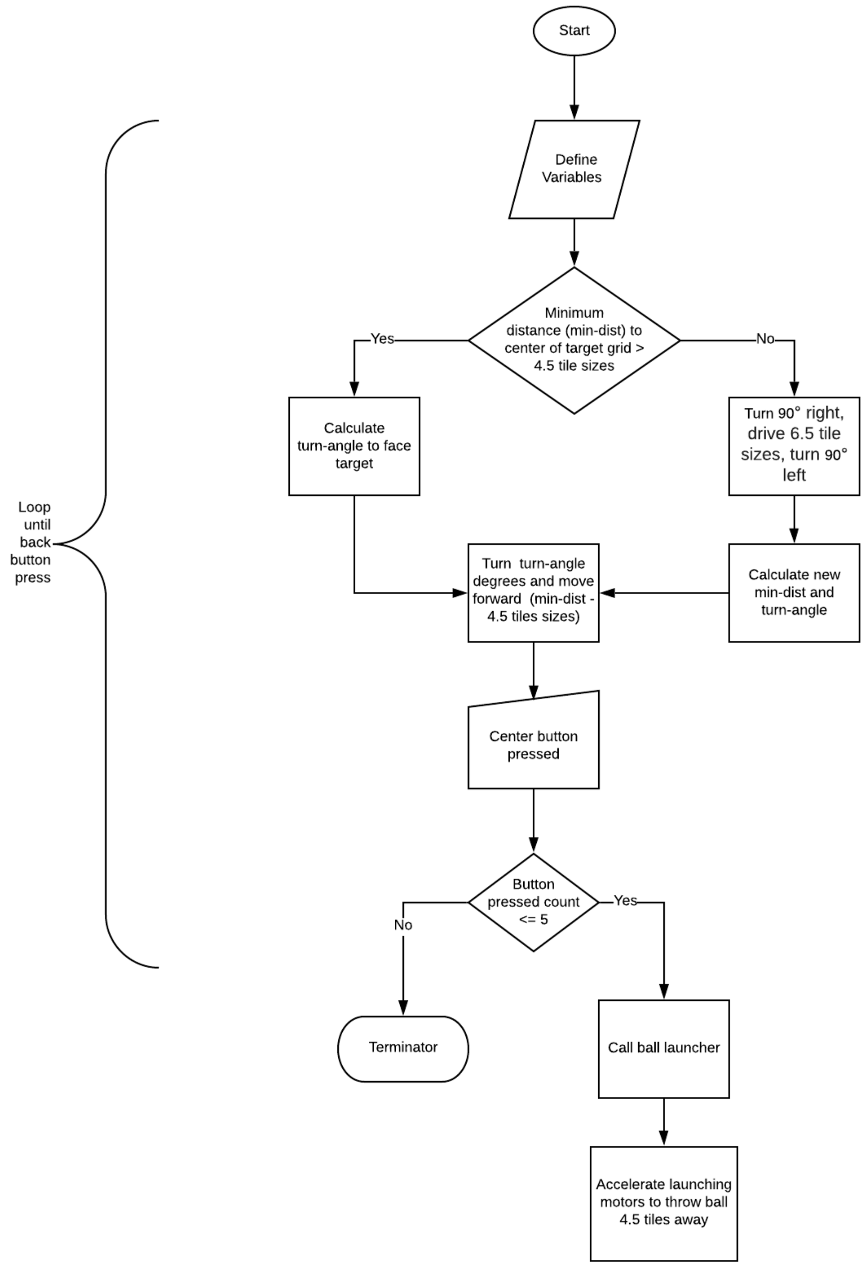

Figure 4: Navigation and Launcher

1.3 – Design choices before arriving at final design

The first design for the launcher was very similar to a simple catapult. The speed of the ball as well as its total travel distance greatly depend on the speed of the motors powering the launcher. The angle at which that same launcher was initially positioned also had a large effect in the distance traveled. This design gave very poor results as it would most often throw a ball at only about 90 cm. Elongating the launcher arm proved to be a very inefficient solution as it also increased its weight and the needed speed to launch the ball. The launcher motors were also previously positioned vertically and towards the back of the EV3 brick, which affected the weight distribution of the robot.

Section 2: Test Data

Table 1. Test data for stationary launch

Trial	(x, y) (cm)	Total Displacement (cm)
1	(0.00, 135.15)	135.15
2	(3.01, 134.63)	134.66
3	(-2.10, 137.95)	138.01
4	(-2.06, 135.16)	135.20
5	(0.42, 133.62)	133.62
6	(0.31, 128.47)	128.48
7	(0.70, 133.60)	133.61
8	(1.35, 130.39)	130.45
9	(1.37, 123.62)	123.68
10	(2.62, 128.36)	128.71
11	(1.20, 140.60)	140.62
12	(2.43, 134.85)	134.91
13	(-4.03, 128.31)	128.38
14	(-1.41, 124.94)	124.96
15	(1.02, 134.87)	134.89
16	(-1.90, 134.70)	134.75
17	(0.42, 135.76)	135.77
18	(-1.93, 130.92)	130.96
19	(-2.30, 133.45)	133.51
20	(-5.01, 129.82)	129.98

Table 2. Test data for mobile launch

Trial	Actual Launch Position (x, y) (cm)	Ball land Position (x, y) (cm)
1	(60.21, 84.26)	(149.17, 184.72)
2	(61.33, 83.25)	(149.63, 186.61)
3	(58.74, 83.70)	(132.66, 185.76)
4	(65.13, 75.29)	(129.63, 191.82)
5	(62.01, 73.50)	(125.95, 187.60)
6	(62.53, 88.35)	(127.96, 193.88)
7	(57.36, 81.52)	(126.94, 196.81)
8	(64.71, 86.31)	(122.90, 206.39)
9	(55.90, 87.29)	(125.85, 206.65)
10	(65.35, 73.85)	(124.93, 200.32)

Table 3: Total displacement of the ping pong ball, as seen from the mobile launch

Trial	Displacement (x,y)	Total displacement
1	(88.96, 100.46)	134.14
2	(88.3, 103.25)	135.85
3	(73.92, 102.06)	126.01
4	(64.5, 116.53)	133.18
5	(63.94, 114.1)	130.79
6	(65.43, 105.53)	124.17
7	(69.58, 115.29)	134.62
8	(58.19, 120.08)	133.44
9	(69.95, 119.36)	138.35
10	(59.58, 126.47)	139.80

Section 3: Test Analysis

The following formulas are used to analyze the required mean and standard deviations:

$$\left(x_\mu, y_\mu\right) = \left(\frac{\sum_{i=1}^{N} x_i}{N}, \frac{\sum_{i=1}^{N} y_i}{N} \right)$$

N: The total amount of sample points

x_i: The x coordinate of the i^{th} sample point

y_i: The y coordinate of the i[th] sample point

x_μ: The mean of x coordinate

y_μ: The mean of y coordinate

$$(x_\sigma, y_\sigma) = \left(\sqrt{\frac{\sum_{i=1}^{N}(x_i - x_\mu)^2}{N-1}}, \sqrt{\frac{\sum_{i=1}^{N}(y_i - y_\mu)^2}{N-1}} \right)$$

N: The total amount of sample points

x_i: The x coordinate of the i[th] sample point

y_i: The y coordinate of the i[th] sample point

x_μ: The mean of x coordinate

y_μ: The mean of y coordinate

x_σ: The standard deviation of x coordinate

y_σ: The standard deviation of y coordinate

Table 4: The mean and standard deviations of the 2 launches

Launch Type	Mean (x_μ, y_μ) (cm)	Standard Deviation (x_σ, y_σ) (cm)
Stationary Launch	(-0.29, 132.46)	(2.20, 4.26)
Mobile Launch	(70.245, 112.31)	(10.21, 8.45)

Sample calculation (the mean and standard deviation of Stationary Launch):

$$x_\mu = \frac{0.00 + 3.01 + (-2.10) + \cdots + (-1.93) + (-2.30) + (-5.01)}{20} = -0.29$$

$$y_\mu = \frac{135.15 + 134.63 + 137.95 + \cdots + 130.92 + 133.45 + 129.82}{20} = 132.46$$

$$x_\sigma = \sqrt{\frac{(0.00 - (-0.29))^2 + \cdots + ((-5.01) - (-0.29))^2}{19}} = 2.20$$

$$y_\sigma = \sqrt{\frac{(135.15 - 132.46)^2 + \cdots + (129.82 - 132.46)^2}{19}} = 4.26$$

Confidence interval = $\bar{x} \pm (z^* * \frac{\sigma}{\sqrt{n}})$

For the stationary launch:

z* = 1.96

n = 20

$$\sigma = \sqrt{2.20^2 + 4.26^2} = 4.79cm$$

$$\bar{x} = \sqrt{-.29^2 + 132.46^2} = 132.46cm$$

Confidence interval = $132.46 \pm (1.96 * \frac{4.79}{\sqrt{20}})$ = 132.46 ± 2.093cm

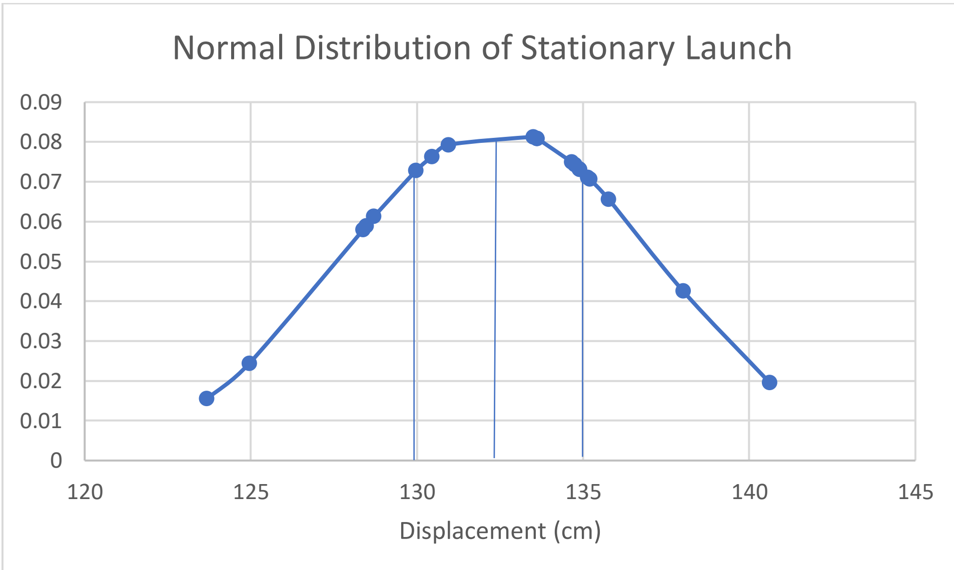

Figure 5: plot of the displacement in a normal distribution. The area between the outer most curves is considered to be in the 95% range of confidence. Notice how most of the values are contained in that range.

For the mobile launch:

z* = 1.96

n = 10

$$\sigma = \sqrt{10.21^2 + 8.45^2} = 13.25cm$$

$$\bar{x} = \sqrt{70.245^2 + 112.31^2} = 132.47cm$$

Confidence interval = $132.47 \pm (1.96 * \frac{13.25}{\sqrt{10}})$ = 132.47 ± 8.21cm

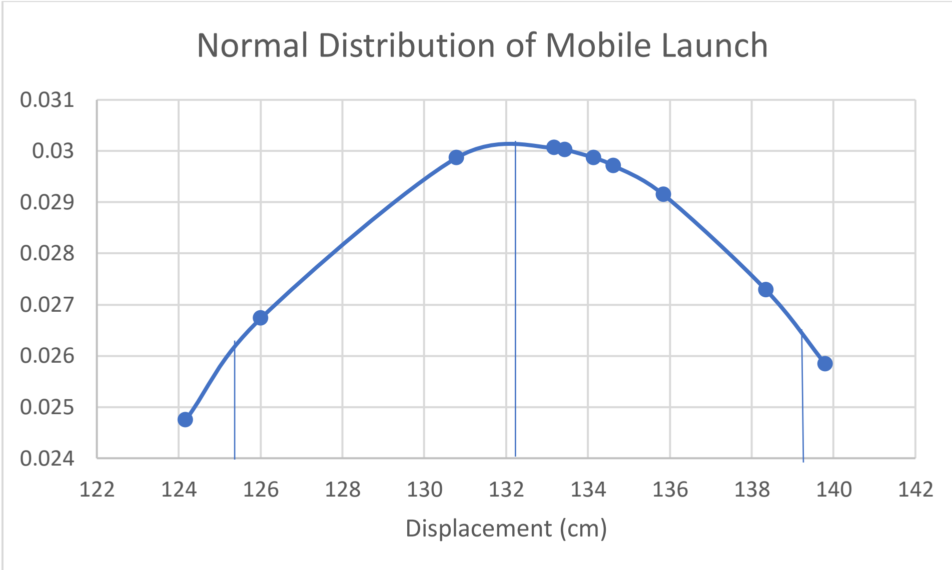

Figure 6: Graph of the normal distribution of the mobile launch. Notice how the area of 95% confidence is much larger than that of the stationary launch.

Section 4: Observations and Conclusions

The statistic most closely related to repeatability of the mechanism is the standard deviation. The mean indicates how far that the ball will go on average, but does not give insight into how precise the launch is. For repeatability, the distance of the ball launched is largely irrelevant as long as it meets the requirement: precision and tendency to launch to the required location is much more important.

From the results above, it can be concluded that our launcher is very precise; however, for the case of the mobile launcher, it is not very accurate. It is interesting to note that although the deviation is much different between the mobile and stationary launcher, they both have an almost identical mean displacement distance. The only variance seems to be based on the navigation of the mobile robot to reach the launching point, and its relative orientation and location at that point. This makes sense, and accounts for the difference in confidence interval between the 2 different classes of launch.

Independently, there is minimal to no difference between the static launch and the mobile launch when we set the final position of the robot to be at (0,0). This is because the launcher is doing the same task with the stationary launch as it does with the mobile launch, the only difference being the point and angle where the ball is launched from. The total distance launched would not be sensitive to error in either trial; however, the final displacement would be much more sensitive to error in the mobile launch when compared to the stationary launch as indicated by the calculations in statistical analysis above.

The probability of success given a confidence level of +- 15cm is as follows:

For the stationary launch:

$$15 = (z^* * \frac{4.79}{\sqrt{20}})$$

$z^* = 14.00$

From a z-score table, since z* > 3.4, p is 100%

For the mobile launch:

$$15 = (z^* * \frac{\sigma}{\sqrt{10}})$$

$$15 = (z^* * \frac{13.25}{\sqrt{10}})$$

z* = 3.58

From a z-score table, p is nearly 100%

Section 5: Further Improvements

The biggest changes to our design that would contribute to repeatability of results would be to ensure that the gears have a stronger connection to each other and are not able to separate. If they separate, they do not generate the maximum acceleration and therefore velocity that is needed to get the ball a distance that is repeatable over multiple efforts.

Another improvement that would be made to improve the launcher would be to have a designated starting point for each throw. Currently, the launcher rests on the cables when it is in its lowest position. While the launcher arm does not apply much pressure to the cables, it does cause them to compress and results in a slightly inconsistent starting position when considered over multiple attempts for the launcher to throw the ball.

It may also be beneficial to use stored energy instead of instantaneous power to fire the ping pong ball when taking the final lab into consideration. Using both of the motors to accelerate quickly is draining on the battery, and may cause inconsistent attempts to fire the ping pong balls during the demo. It will also affect the navigation of the robot, reducing accuracy of the inputs noticeably when the robot returns to the starting position.

The minimum number of trials required for one success using the Binomial distribution is as follows:

Stationary:

$\bar{X}$ = np = 132.46

σ^2 = npq = 4.79^2 =22.94

q= $\frac{22.94}{132.48}$ = 0.173

P = 1-q = 0.827

So, n=$\frac{132.46}{.827}$ = 160.2 = 161 trials to guarantee one success.

Mobile:

$\bar{x}$ = np = 132.47

σ^2 - npq = 13.25^2 = 175.56

$$Q = \frac{175.56}{132.47} = 1.32$$

$$P = 1 - q = -0.32$$

So $n = \frac{132.27}{-.32} = -413.34 = -414$ trials to guarantee one success

*disclaimer: this should be a positive value, but a low standard deviation lead to a negative value.