ECSE 211 - Design Principles and Methods

Testing Document

GROUP 11
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Abstract

This document will outline the tests in preparation for the final competition. The purpose of this document is to outline the tests done, show the recorded values for each test and present the evaluations for each test result.

Contents

1 EDIT HISTORY

- Monday February 27th:
  - **Ian Smith:** initial set-up of document and start of Test 1 (section 2.1)
- Week of Feb 27 - 5th:
  - **Ian Smith:** Completion of Test 1 (section 2.1)
- Wednesday March 8th
  - **Alex Lam:** General formatting
- Saturday March 12th
  - **Ian Smith:** Ultrasonic and Light sensors testing results (section 2)
- Thursday March 16th:
  - **Durham Abric:** Added test data, remarks, formatting (section 6.1.1)
- Thursday March 16th:
  - **Ian Smith:** Added Testing data for Localization and testing description for sections 2.2, 2.3 and 3.1.
- Thursday March 22nd:
  - **Alex Lam:** Added test description and data for tests performed on the throwing arm release angle (section 6.2)
- Tuesday March 28th:
  - **Alex Lam:** Re-organised and added test data for all parts and localization tests
- Wednesday March 29th:
  - **Ian Smith:** Added context for sections 4, 5 and 6.
  - **Alex Lam:** Added in test data for sections 4, 5 and 6
- Friday April 7:
  - **Ian Smith:** Completed sections 7 and 8.

2 Parts Testing

2.1 Motors

This subsection will contain all the results of all tests done on the motors.

2.1.1 Motors test 1:

- **Date:** February 27, 2017
- **Tester:** Ian Smith
- **Purpose:** To make sure all motors were operational, determine the level of functionality of each motor and select the 4 best motors to be used in the construction of the robot.
- **Test Description:** Only 4 NXT Motors and 4 EV3 Motors will be tested as, at the time of this test, only 2 mindstorm kits were available.Testing will be done by having each motor timed for a rotation of 360 degrees at a fixed velocity (using the default testing features of the ev3 brick). 5 trials will be done for each motor and then the mean will be calculated. The mean will be used to determine which motors will be used. All measured and calculated values are in seconds (s).
- **Test Data:**

Table 1: Nxt Motors Time per revolution

Trial	Motor 1(s)	Motor2 (s)	Motor 3 (s)	Motor 4 (s)
1	2.62	2.64	2.65	2.72
2	2.54	2.62	2.65	2.76
3	2.91	2.56	2.53	2.56
4	2.48	2.68	2.64	2.74
5	2.58	2.57	2.68	2.60

  - Motor 1: $\mu = 2.62$ s
  - Motor 2: $\mu = 2.61$ s
  - Motor 3: $\mu = 2.63$ s
  - Motor 4: $\mu = 2.68$ s

(see glossary of terms for a description of the mean (μ) and standard deviation (σ)

Table 2: Ev3 Motor times per Revolution 5 - 8

Trial	Motor 5 (s)	Motor 6 (s)	Motor 7 (s)	Motor 8 (s)
1	2.54	2.59	2.51	2.54
2	2.50	2.60	2.60	2.49
3	2.55	2.63	2.58	2.69
4	2.56	2.60	2.59	2.55
5	2.56	2.68	2.53	2.49

  - Motor 5: $\mu = 2.54$ s
  - Motor 6: $\mu = 2.62$ s
  - Motor 7: $\mu = 2.56$ s
  - Motor 8: $\mu = 2.55$ s

- **Conclusion:** Motors 1, 2, 5 and 8 will be used for the project due to their fast rotation rate Sources of Error: Incomplete definition - The measurement for the rotations are not defined. The reaction time of the person controlling the stopwatch needs to be taken into consideration.

2.2 Ultrasonic Sensor

This section will contain testing data related to the ultrasonic sensors.

2.2.1 Ultrasonic sensor test 1:

- **Date:** March 12, 2017.
- **Tester:** Ian Smith
- **Purpose:** To test the performance level of the different US sensors in order to determine which sensor to use in the construction of the robot.
- **Test Description:** The different sensors will be place a known distance away from a wall and the distance shown on the brick will be recorded.
- **Test Data:**

Table 3: Ultrasonic Sensor Readings

Trial	Distance (cm)	Sensor 1 (cm)	Sensor 2 (cm)	Sensor 3 (cm)
1	30.48	30.45	30.84	29.81
2	60.96	61.80	61.42	62.22
3	91.44	90.74	92.10	92.30
4	121.92	122.71	122.75	121.72

Table 4: Ultrasonic Sensor Error

Trial	Sensor 1 Error (cm)	Sensor 2 Error (cm)	Sensor 3 Error (cm)
1	0.03	-0.36	0.67
2	-0.84	-0.46	-1.26
3	0.70	-0.66	-0.86
4	-0.79	-0.83	0.20

The Mean and Standard Deviations of the ultrasonic sensor errors are shown below:

- Means:
  * Sensor 1: μ = -0.225 cm
  * Sensor 2: μ = -0.5775 cm
  * Sensor 3: μ = -0.3125 cm
- Standard deviations:
  * Sensor 1: σ = 0.64 cm
  * Sensor 2: σ = 0.18 cm
  * Sensor 3: σ = 0.78 cm

- **Conclusion:** Sensors 1 and 3 will be used as they have the smallest error means.

2.3 Light Sensor

2.3.1 Light sensor Test 1:

- **Date:** March 12, 2017.
- **Tester:** Ian Smith
- **Purpose:** To record the level of performance of the light sensors and determine the sensor readings for the different surfaces
- **Test Description:** The light sensors will be tested using the Red test function found on the EV3 brick. We will be testing the accuracy of the light sensors by recording the values displayed on the EV3 brick while the sensor is over a tile and a black line.

- **Test Data:**

Table 5: Light Sensor Tiles

Trial	Sensor 1 (Red Values)	Sensor 2 (Red Values)
1	0.79	0.7
2	0.82	0.67
3	0.85	0.73
4	0.77	0.72
5	0.71	0.74

  The mean for each sensor is as follows:

  - Sensor 1: $\mu = 0.79$
  - Sensor 2: $\mu = 0.71$

Table 6: Light Sensor Black Lines

Trial	Sensor 1 (Red Values)	Sensor 2 (Red Values)
1	0.23	0.21
2	0.17	0.23
3	0.30	0.24
4	0.28	0.27
5	0.29	0.28

  The mean for each sensor is as follows:

  - Sensor 1: $\mu = 0.25$
  - Sensor 2: $\mu = 0.25$

- **Conclusion:** In conclusion, the light sensors work relatively well and the value detected for a black line is 0.25

3 Localization

This is section will contain all tests done on localization as well as corresponding data.

3.1 Timing and Position

This subsection will contain data from all tests that have to do with the duration of the localization procedure.

3.1.1 Localization Test 1: Initial Build

- **Date:** March 13th
- **Tester:** Ian Smith and Alex Lam
- **Purpose:** Determine the effectiveness of our localization as well as if it meets the time requirements set (less than 30 seconds).
- **Test Description:** For every trial the robot will begin in one of the 4 corners. The robots arbitrary start heading will be recorded. Timing of the localization will begin when the robot starts to rotate. The robot will then undergo its localization procedure at the end of which timing will be stopped. The timing of the procedure, the actual end orientation and position on the field of the robot as well as the odometer readings for these same values (orientation and position) will then be recorded. In the following data, Start θ will represent the starting position of the robot before localization. The End θ (Position) is the actual orientation of the robot after localization which was measured using a protractor. The End θ (Odo) is the value reported by the odometer for the orientation of the robot. Time is how long the robot took for it to end its localization.
  N.B: This first test was done using a very rudimentary build of the robot which did not yet have the shooting arm, the tower on which this arm rests or the motors used to operate the arm.
- **Test Data:** For ease of reading, the data of this test will be split into two tables: one for the data regarding the orientation of the robot and the other containing data on the position of the robot after localization.

Table 7: Localization Orientation and Time, initial build

Trial	Start orientation (°)	End Orientation (°)	Odo End Orientation (°)	Delta T (°)	Time(s)
1	-90.00	Failed	Failed	Failed	18.72
2	-45.00	10.00	0.13	9.87	11.90
3	0.00	-2.00	0.13	2.13	15.07
4	45.00	10.00	0.00	10.00	15.87
5	90.00	-2.00	0.13	2.13	18.06
6	135.00	0.00	0.00	0.00	19.05
7	180.00	0.00	0.13	0.13	35.03
8	180.00	12.00	0.00	12.00	20.37
9	-90.00	14.00	0.26	13.74	23.49
10	-45.00	1.00	0.13	0.87	22.40
11	-135.00	-2.00	0.26	2.26	22.24
12	-90.00	1.00	0.26	0.74	24.18
13	-45.00	3.00	0.00	3.00	12.50
14	0.00	1.00	0.00	1.00	14.57
15	45.00	-2.00	0.00	2.00	16.26
16	90.00	0.00	0.26	0.26	17.88
17	135.00	0.00	0.13	0.13	19.64
18	180.00	0.00	0.39	0.39	20.12

N.B: Trials 1 - 9 were done with the original version of the localization code, which presented errors that caused the localization to either fail or take longer than the allowed 30 seconds. The localization code was then altered and this improved version of software was used for trials 10 through 18 which were all successful and well under the 30 second limit in duration.

The means for end orientation and duration of trials 10-18 are as follow:

- $\mu_\theta = 0.22°$
- $\mu_{time} = 18.87s$

Table 8: Localization Position, initial build

Trial	Odometer X	Odometer Y	Actual X	Actual Y	Δ X	Δ Y
1	Failed	Failed	Failed	Failed	Failed	Failed
2	-16.77	-13.19	-15.00	-13.60	1.77	0.41
3	-14.12	-13.93	-13.80	-13.50	0.32	0.43
4	-11.38	-11.37	-11.00	-11.30	0.38	0.07
5	-13.16	-16.06	-12.80	-15.70	0.36	0.36
6	-13.17	-16.08	-12.20	-15.50	0.97	0.58
7	-15.80	-17.90	-13.90	-17.50	1.90	0.40
8	-15.28	-17.67	-13.20	-17.60	2.08	0.07
9	-18.47	-15.07	-16.50	-15.50	1.97	0.43
10	-13.97	-14.16	-13.40	-14.20	0.57	0.04
11	-17.72	-17.91	-16.40	-17.10	1.32	0.81
12	-15.27	-16.72	-14.70	-16.30	0.57	0.42
13	-16.78	-12.77	-15.60	-12.60	1.18	0.17
14	-13.57	-12.27	-13.00	-12.20	0.73	0.07
15	-14.09	-13.37	-13.10	-12.70	0.27	0.67
16	-13.57	-15.04	-13.10	-14.90	0.47	0.14
17	-11.38	-15.09	-10.80	-14.70	0.58	0.39
18	-14.37	-15.76	-14.00	-15.40	0.37	0.36

The means for the odometer error in x and y values are as follows:

- $\mu_X = 0.93$
- $\mu_Y = 0.34$

- **Conclusion:** The updated versions of our localization code works effectively with variable starting orientations and respects the given time constraints.

3.1.2 Localization Test 2: Updated build

- **Date:** March 20, 2017
- **Tester:** Ian Smith and Alex Lam
- **Purpose:** To determine the effects of the different build on the effectiveness of our localization method for different starting angles.

- **Test Description:** The test procedure is identical to that of Localization Test 1 with the slight difference that the starting angles will no longer be arbitrarily determined by the tester. The Starting orientation the robot will begin at 0° and will be increased by increments of 45° until 315°. This test will also be performed on a different build of the robot (see hardware document Design 4 for specifications). This build differs from the primary build used in the first test by the addition of 2 ultrasonic sensors, 2 light sensors, a throwing arm, the tower on which the arm is supported and 2 extra NXT motors to power the arm.

- **Test Data:** No changes were done to the localization code between this test and the previous localization test.

Table 9: Localization Orientation and Time, Design 4

Trial	Start orientation (°)	End Orientation (°)	Odo End Orientation (°)	Delta T (°)	Time(s)
1	0.00	2.00	0.13	1.87	14.85
2	45.00	1.00	0.00	1.00	16.36
3	90.00	0.00	0.13	0.13	18.20
4	135.00	5.00	0.13	4.87	20.41
5	180.00	4.00	0.26	3.74	21.30
6	225.00	3.00	0.13	2.87	22.91
7	270.00	1.00	0.00	1.00	26.08
8	315.00	3.00	0.00	3.00	12.87

The means for the duration of the localization procedure and the difference between the robots final orientation and the final odometer reading are as follows:

  - $\mu_{\Delta\theta} = 2.31°$
  - $\mu_{time} = 19.12$s

Table 10: Localization Position, Design 4

Trial	Odometer X	Odometer Y	Actual X	Actual Y	delta X	delta Y
1	-19.87	-17.56	-15.10	-14.20	4.77	3.36
2	-18.58	-17.57	-14.10	-17.40	4.48	0.17
3	-18.58	-19.82	-14.00	-18.50	4.58	1.32
4	-16.77	-20.37	-12.50	-20.10	4.27	0.27
5	-18.47	-19.47	-13.50	-20.00	4.97	0.53
6	-21.27	-21.47	-15.20	-18.00	6.07	3.47
7	-20.38	-20.34	-16.20	-19.00	4.18	1.34
8	-18.78	-19.67	-13.90	-17.80	4.88	1.87

The means for the odometer error in x and y values are as follows:

  - $\mu_X = 4.78$
  - $\mu_Y = 1.54$

- **Conclusion:** In conclusion the added weight of the extra components significantly alters the effectiveness and accuracy of our localization procedures. Although this error is significant, we are confident that the corrections implemented will allow the robot to perform well beyond expectations (see software document section 3.4 for details).

3.2 Odometer and Positioning

This section will cover tests done on the position of the robot on the field vs the odometer's recorded position after localization.

This test was done using a build of the robot which did not have the throwing arm or the two motors that are used to operate it. This test was done on March 13, 2017.

Table 11: Odometer vs Actual Position

Trial	Actual X (cm)	Actual Y (cm)	Odometer X (cm)	Odometer Y (cm)
1	-14.9	-17.5	-15.8	-17.9
2	-11.0	-11.3	-11.3	-11.4
3	-15.0	-13.6	-16.8	-13.2
4	-12.2	-15.4	-13.2	-16.1
5	-13.2	-17.6	-15.3	-17.6
6	-16.5	-15.5	-18.7	-15.1
7	-13.4	-14.2	-13.9	-14.2
8	-13.0	-12.2	-13.6	-12.3
9	-13.1	-12.7	-14.1	-13.4
10	-13.1	-14.9	-13.6	-15.0
11	-10.8	-14.7	-11.4	-15.1
12	-14.0	-14.7	-14.4	-15.8
13	-16.4	-17.1	-17.7	-17.8
14	-14.7	-16.3	-15.3	-16.7
15	-15.6	-12.6	-16.8	-12.8

The average error in the x direction is 0.67cm and the average error in the y direction is 0.34cm. These errors are insignificant and we will be using this method to test the final build of the robot.

This test was done using the final build of the robot which consists of 4 motors, 2 ultrasonic sensors and 2 light sensors. This test was done on March 20, 2017.

Table 12: Odometer vs Actual Position

Trial	Actual X (cm)	Actual Y (cm)	Odometer X (cm)	Odometer Y (cm)
1	-15.1	-14.2	-19.9	-17.6
2	-14.1	-17.4	-18.6	-17.6
3	-14.0	-18.5	-18.58	-19.82
4	-12.5	-20.1	-16.8	-20.4
5	-13.5	-20.0	18.5	-19.5
6	-15.2	-18.0	-21.7	-21.5
7	-16.2	-19.0	-20.4	-20.3
8	-13.9	-17.8	-18.8	-19.7

Conclusion: The average error in the x direction is 4.8cm and the average error in the y direction is 1.5cm. The addition of the other parts significantly increased the error of the actual positioning. This problem is corrected after the robot exits the first tile it was placed in. The robot will correct the odometer reading when the light sensors detect the black lines on the grid which are a known distance.

4 Navigation

This section will cover test data regarding the movement of the robot on the playing field. The robot's navigateTo method will be the focus of these tests. The robot will be told to travel to specific coordinates and the actual measurement will

4.1 Obstacle Avoidance and Odometry

4.1.1 Test 1: Navigating around Obstacles

- **Date:** March 27, 2017
- **Tester:** Ian Smith and John Wu
- **Purpose:** To determine how accurate the odometer and mapping of the robot is when needed to avoid obstacles.
- **Test Description:** The test was done by asking the robot to move travel to the center of a specific square. The each possible starting corner of the robot was tested along with navigation. The robot's navigation was tested with the arm retracted and also in the rest position. The actual x and y position of the robot was recorded along with the x and y positions shown by the odometer. The robot was required to localize before each trial to orient itself properly and get it's initial position.
- **Test Data:** For each trial the starting position and the square being asked to travel to is recorded. The measured X and Y values on the grid were recorded along with odometer's X and Y readings. The difference between the measured and odometer values are calculated and recorded. All calculated and measured values are in cm. Lastly the battery life of the robot before each trial was recorded.

Table 13: Navigation with Obstacle avoidance

Trial	Start	Travel To	Actual X	Actual Y	Odometer X	Odometer Y	Delta X	Delta Y	Battery
1	(0,0)	(3,1)	76.56	17.20	75.32	16.65	1.24	0.55	6.90
2	(0,0)	(3,1)	77.96	14.00	75.17	14.40	2.79	-0.40	6.80
3	(0,0)	(3,1)	76.36	20.40	75.21	16.01	1.15	4.39	6.80
4	(11,0)	(8,1)	Failed	Failed	Failed	Failed	Failed	Failed	6.80
5	(11,0)	(8,1)	Failed	Failed	Failed	Failed	Failed	Failed	6.80
6	(11,0)	(8,1)	233.16	21.50	229.83	15.52	3.33	5.98	6.70
7	(11,0)	(8,1)	233.76	22.80	229.19	15.69	4.57	7.11	6.50
8	(11,0)	(8,1)	231.76	19.10	228.01	16.07	3.75	3.03	8.00
9	(11,11)	(10,8)	236.46	226.86	287.32	228.19	-50.86	-1.33	7.90
10	(11,11)	(10,8)	221.36	241.36	290.92	229.14	-69.56	12.22	7.80
11	(11,11)	(10,8)	222.86	241.36	289.77	230.00	-66.91	11.36	7.80
12	(11,11)	(10,8)	238.76	234.26	287.93	234.98	-49.17	-0.72	7.80
13	(0,11)	(1,8)	15.40	234.96	14.77	229.46	0.63	5.50	7.60
14	(0,11)	(1,8)	15.50	234.56	14.80	229.49	0.70	5.07	7.50
15	(0,11)	(1,8)	15.00	234.76	13.94	229.30	1.06	5.46	7.50

- **Conclusion:** The results from testing the robot's navigation with obstacle avoidance provided much needed information for finalizing the design. Trials 4 and 5 failed due to the robot being placed in corner 2 but the robot was programed to be placed in corner 1. After the adjustment, the robot operated as expected until trials 9 to 12 where we noticed a large error in the odometer's X values. This problem was caused by the retracted arm making contact with the obstacle and occasionally the wall. After placing the robot's arm in the rest position the error in the X values decreased to below 2 cm. The conclusion drawn from these tests are that the coding for obstacle avoidance works but the robot will need to be tested for AA batteries which will be used for the competition.

5 Ball Retrieval

5.1 Picking up and loading ball

5.1.1 Ball retrieval Test 1:

- **Date:** March 28, 2017
- **Tester:** Ian Smith
- **Purpose:** This test was done to see if the initial code and parameters for ball retrieval works.
- **Test Description:** The robot will be given its starting corner and the position of the ball dispenser as parameters. An obstacle was placed in different positions for these tests. The angle the robot needs to raise its arm to retrieve the ball will be changed if needed throughout the test. The robot was also told the orientation of the ball dispenser at the start of each trial.

- **Test Data:** For each trial the ball dispenser's position will be recorded along with the angle the arm will need to move to retrieve the ball. the location of the obstacle will also be recorded if one is placed on the field. The orientation of the ball dispenser is recorded. The result of each test is recorded based on completion. A successful run is considered when the robot reaches the ball dispenser and is able to retrieval a ball after beeping, which signifies it is ready to receive one. A run is considered failed if the robot can not retrieval the ball or signal that it is ready to receive the ball.

Table 14: Navigation and Ball Retrieval

Trial	**Dispenser Position**	**Angle of Arm (degrees)**	**Obstacle Location**	**Orientation**	**Result**
1	(-1,6)	47	(0,3)	E	Success
2	(-1,6)	47	(0,3)	E	Success
3	(-1,6)	47	(0,5)	E	Fail
4	(-1,6)	47	(0,5)	E	Fail
5	(-1,6)	47	(0,5)	E	Fail
6	(-1,6)	47	(0,3)	E	Success
7	(-1,6)	47	(0,5)	E	Success
8	(-1,6)	47	(0,5)	E	Fail
9	(-1,6)	47	(0,5)	E	Success
10	(5,-1)	47	(2,0)	E	Fail
11	(5,-1)	47	(2,0)	N	Fail
12	(5,-1)	47	(2,0)	N	Fail
13	(5,-1)	47	None	N	Fail
14	(5,-1)	47	None	N	Success
15	(5,-1)	47	None	N	Fail
16	(5,-1)	47	None	N	Success
17	(5,-1)	47	(3,0)	N	Success

- **Conclusion:** Based on the results from testing ball retrieval an angle of 47 degrees is ideal for ball retrieval. Trials 3, 4, 5, 10, 11, 12, 13 and 14 failed due to a threading error. One motor of the robot would suddenly begin to accelerate causing the robot leave its path and become lost on the field, not being able to align itself with the ball dispenser. Trial 8 failed due to the alignment of the robot being slightly off. To conclude, the robot's ball retrieval method works as intended but there is still an issue regarding the multiple threads being turned on and off. This is causing the robot to accelerate sporadically during navigation.

6 Shooting ball

6.1 Distance

6.1.1 Shooting Test 1: Preliminary design

- **Date:** March 12, 2017
- **Tester:** Durham Abric
- **Purpose:** To obtain proof of concept and/or calibrate the the throwing mechanism for the initial mechanical design.
- **Test Description:** The throwing mechanism from the initial mechanical design (See Hardware Document Design version 1) was detached from the robot and mounted firmly to the wooden-field surface, with the motor in contact with the surface. The mechanism was then tested with different motor accelerations and distance of rotations, recording the distance at which the ball first bounced for each trial.
- **Test Data:** The acceleration and rotation of the motors that were programed into the robot were recorded for each run. The acceleration was recorded in degrees per second squared. The Motor Rotation is recorded in degrees. The distance thrown was also recorded. in cm.

Table 15: Throw Distance of Initial Design

Trial	Motor Acceleration (deg/s/s):	Motor Rotation (deg)	Distance Thrown (cm) (±5cm)
1	1500	75	50
2	1750	75	55
3	2000	75	50
4	2250	75	50
5	2500	75	60
6	2750	75	55
7	3000	75	55
8	3250	75	55
9	3500	75	55
10	3750	75	55
11	4000	75	55
12	1500	90	60
13	1750	90	65
14	2000	90	65
15	2250	90	65
16	2500	90	65
17	2750	90	70
18	3000	90	65
19	3250	90	65
20	3500	90	65
21	3750	90	70
22	4000	90	70
23	1500	105	65
24	1750	105	65

Trial	Motor Acceleration (deg/s/s):	Motor Rotation (deg)	Distance Thrown (cm) (±5cm)
25	2000	105	70
26	2250	105	70
27	2500	105	70
28	2750	105	70
29	3000	105	65
30	3250	105	75
31	3500	105	75
32	3750	105	75
33	4000	105	70
34	1500	120	60
35	1750	120	60
36	2000	120	60
37	2250	120	60
38	2500	120	60
39	2750	120	65
40	3000	120	65
41	3250	120	65
42	3500	120	65
43	3750	120	65
44	4000	120	65

- **Conclusions:** Our current (March 12, 2017) ball launching mechanism doesn't have the ability to launch the ball the necessary distance to succeed in the competition. This appeared to be caused by a small range of motion (ROM) on which to do work on the ball. As a result, we have moved forward to design a new launching mechanism; it will have a larger ROM. We will use this test as a benchmark for further success/failure.

6.1.2 Shooting test 2: Version 3

- **Date:** March 21st
- **Tester:** Alex Lam
- **Purpose:** To determine the viability of the new hardware design (see hardware document section 7.3)
- **Test Description:** For the purpose of this test a special program was designed that allows the dynamic change of the angle at which the motors of the throwing arm are set to rotate to fire the ball. To avoid unnecessary testing only the furthest testing range will be tested (a distance of 8 tiles). After having placed the robot at a distance of 8 tiles the tester will perform 7 test trials for every increment of 5° starting at 130°. A successful trial is described as the event where the robot scores a shot on the goal. The results of the trials (success or failure) are recorded in the following table along with the battery level of the EV3 brick at the time of the trial.
- **Test Data:**

Table 16: 8 Tiles

Angles	Success (Battery Level)					
110	-	-	-	-	-	-
120	-	-	-	-	-	-
125	-	-	-	-	-	-
130	No(7.9)	No(7.9)	No(7.9)	-	-	-
135	No(7.8)	Yes(7.8)	No(7.8)	No(7.8)	Yes(7.7)	No(7.7)
140	Yes(7.7)	Yes(7.7)	No(7.7)	No(7.7)	No(7.6)	No(7.6)
145	No(7.6)	No(7.6)	No(7.6)	No(7.6)	No(7.5)	No(7.5)
150	-	-	-	-	-	-

- **Conclusion:** In conclusion the 2 motor design still does not provide enough power to consistently make the shot from a distance of 8 tiles. It was thus concluded that rubber bands were to be used in order to increase the amount of power the throwing arm could deliver.

6.2 Release angle

6.2.1 Angle Calibration Test 1:

- **Date:** March 22nd
- **Tester:** Ian Smith, Alex Lam and Ethan Lague
- **Purpose:** To calibrate the throwing arm for different target distances
- **Test Description:** The target will stay in place and test throws will be performed starting at the 5 tile line and moving back until the 8 tile mark. In order to complete this test a special throwing arm program was developed which allowed for the angle of rotation of the motors to be modified in between throws which will allow for the ideal release angle to be found for each of the mentioned distances. At each one of the distance benchmarks, 7 trial throws will be performed for different release angles starting at an angle of 110 degrees and moving forward by increments of 5 degrees until 150 degrees or until the test is no longer deemed relevant (aka until the ideal release angle has been determined). The success or failure of each throw along with the battery level of the brick at the time of the trials will be recorded in separate tables for every distance. The speed of the arm was determined using the getmaxspeed function. This test was performed on the final design build of the robot design (see hardware document section 8).
- **Test Data:** The results of each shot for a specific angle was recorded along with the battery life after the shot.

Table 16: 5 Tiles

Angles	Success (Battery Level)					
110	Yes(7.6)	Yes(7.6)	No(7.6)	Yes(7.5)	-	-
120	No (7.6)	Yes(7.5)	No (7.5)	No (7.4)	No (7.4)	No (7.4)
125	Yes(7.4)	No(7.1)	Yes(7.1)	Yes(7.1)	Yes(7.1)	Yes(7.0)
130	Yes(7.2)	No(7.1)	Yes(7.1)	Yes(7.1)	Yes(7.1)	No(7.0)
135	No	No	No	No	No	No
140	-	-	-	-	-	-
145	-	-	-	-	-	-
150	-	-	-	-	-	-

Table 17: 6 Tiles

Angles	Success (Battery Level)					
110	No	No	No	No	No	No
120	No	No	No	No	No	No
125	-	-	-	-	-	-
130	-	-	-	-	-	-
135	Yes(7.9)	Yes(7.9)	Yes(7.9)	Yes(7.9)	Yes(7.9)	Yes(7.8)
140	-	-	-	-	-	-
145	-	-	-	-	-	-
150	-	-	-	-	-	-

Table 18: 7 Tiles

Angles	Success (Battery Level)					
110	-	-	-	-	-	-
120	-	-	-	-	-	-
125	-	-	-	-	-	-
130	-	-	-	-	-	-
135	Yes(7.8)	Yes(7.8)	Yes(7.8)	Yes(7.8)	Yes(7.8)	Yes(7.8)
140	Yes(7.7)	Yes(7.7)	Yes(7.7)	Yes(7.7)	Yes(7.7)	Yes(7.7)
145	-	-	-	-	-	-
150	-	-	-	-	-	-

Table 19: 8 Tiles

Angles	Success (Battery Level)					
110	-	-	-	-	-	-
120	-	-	-	-	-	-
125	-	-	-	-	-	-
130	-	-	-	-	-	-
135	No (7.6)	No(7.6)	-	-	-	-
140	Yes(7.6)	No(7.6)	Yes(7.6)	Yes(7.6)	Yes(7.6)	Yes(7.5)
145	Yes(7.6)	No(7.6)	Yes(7.5)	Yes(7.5)	Yes(7.5)	No(7.5)
150	-	-	-	-	-	-

- **Conclusion:** The angle needed to be increased the further away the target was. The success of each trial was determined by the angle of the throwing arm and the battery life of the robot. For 5 tiles an angle of 130 degrees is ideal. For 6 tiles an angle of 135 is ideal. For 7 tiles an angle of 140 is ideal. For 8 tiles an angle of 140 is ideal. Further tests will be done using a constant speed which will not be determined by the voltage of the battery.

6.2.2 Angle Calibration test 2:

- **Date:** March 27th
- **Tester:** Ian Smith
- **Purpose:** The purpose of the test is the same as the one done in section 6.2.1 but with speeds that did not vary with the battery life.
- **Test Data:** The results of each shot was recorded with the speed and angle used for the lunching the ball. The region of the minimal bounce area was also recorded.

Table 20: Angles and Speeds for Throwing Arm

Trial	Angle	Speed	Tiles Covered	Bounce Area (w1,w2)
1	100	400	Barely off for 5	(2,2)
2	100	400	Not 5	(2,2)
3	100	400	Not 5	(2,2)
4	100	400	Not 5	(2,2)
5	100	400	Barely 5	(2,2)
6	110	400	5	(2,2)
7	110	400	5	(2,2)
8	110	400	5	(2,2)
9	110	400	5	(2,2)
10	120	400	6	(2,2)
11	120	400	6	(2,2)
12	120	400	6	(2,2)
13	120	400	6	(2,2)
14	120	400	6	(2,2)
15	130	400	7	(2,3)
16	130	400	7	(2,3)
17	130	400	7	(2,3)
18	130	400	7	(2,3)
19	130	400	7	(2,3)
20	140	400	Not 8	(2,5)
21	140	400	Not 8	(2,5)
22	130	500	8	(2,4)
23	130	500	8	(2,4)
24	130	500	Barely 8	(2,4)
25	130	600	8	(2,4)
26	130	600	8	(2,4)
27	130	600	8	(2,4)
28	130	600	8	(2,4)
29	130	600	8	(2,4)

- **Conclusions:** Based on the results we decided to go with set speeds and angles for different numbers of tiles. Trials 20 and 21 failed due to the angle being too high. The ball would bounce too far away from the target and outside the specified zone. All the other failed trials were due to not enough speed or too small of an angle. Based on the two test done for the throwing arm we have decided to use set speeds and angles than the max speed that would be determined by the battery.

7 Offense (System testing)

7.1 Mock trials for Offense

- **Date:** April 4, 2017
- **Tester:** Ian Smith, Alex Lam, John Wu, Durham Abric and Ethan Lague
- **Purpose:** To find possible bugs caused from integrating the different components together. Fine tune the robot for competition standards.
- **Test Description:** The robot will be tested by operating as if it were in the competition. The robot will localize in any corner, retrieve the ball from the ball dispenser at different orientations, travel to a shooting position based on the forward line and shot the ball at the target.
- **Test Data:** The starting corner, ball dispenser position and the result of each trial will be recorded. A description of the result will be recorded.

Table 21: Mock competition trials

Trial	Ball dispenser (bx,by)	Shooting Line	Result
1	(-1,3)	7	Threading error at dispenser
2	(-1,3)	7	Threading error while traveling to shooting position
3	(-1,3)	7	Threading error when retracting arm
4	(-1,3)	7	Traveled to shooting position
5	(-1,2)	7	Threading error at ball dispenser
6	(-1,2)	7	Successful run
7	(-1,2)	7	Successful run
8	(-1,2)	7	Threading error at ball dispenser
9	(-1,2)	7	Successful run
10	(-1,2)	7	Successful run
11	(-1,3)	7	Threading error at ball dispenser
12	(-1,3)	7	Did not travel to shooting position
13	(-1,3)	7	Successful run
14	(-1,3)	7	Failed to localize
15	(-1,3)	7	Failed to localize
16	(-1,3)	7	Failed to retrieve ball
17	(-1,3)	7	Successful run
18	(-1,3)	7	Successful run
19	(-1,2)	7	Successful run
20	(-1,2)	7	Successful run
21	(-1,2)	7	Successful run
22	(-1,2)	7	Successful rune

- **Conclusions:** Trials 1 to 13 were done using the 8 x 8 grid which was available to us for most of the project. The main reason for failure in these trials were threading causing sudden acceleration of a single motor attached to a wheel. There was a single case where the threading error affected one of the motors attached to the throwing arm. Trials 1 to 13 were considered preliminary trials which gave us an idea of how the robot would operate on the larger field. Trials 14 to 22 were done using the fully implemented playing field. For trials 14 and 15 the robot failed to localize due to a change in the threshold used by the ultrasonic sensor. This was to help increase obstacle avoidance but instead caused localization to fail. Trial 17 failed to turning off the Odometry display. The Odometer and Odometry correction both rely on the odometry display. After the odometry display was turned back on and the code was adjusted to reduce the threading problem, trials 17 to 22 ran successfully with the robot localizing in 30s, retrieving the ball from the dispenser while avoiding obstacles, traveling to the shooting position based on the forward line and scoring a goal. All parameters were given through wifi coordinates.

8 Defense

8.1 Mock trials for Defense

- **Date:** April 4, 2017
- **Tester:** Ian Smith, Alex Lam, John Wu, Durham Abric, Ethan Lague and Team 9.
- **Purpose:** Similar purpose to t he offense trials but using different methods.
- **Test Description:** The robot will be tested by operating as if it were in the competition. The robot will localize in any corner and travel to the south edge of the no entry box. The robot will move back and fourth between boxes located at the outside edge of the no entry area and x = 5,6.
- **Test Data:** The starting corner and a description of trial's result will be recorded.

Table 22: Defense Trials

Trial	Corner	Result
1	3	Robot reached intended area and traveled back and forth for 5 mins
2	4	Robot reached intended area and traveled back and forth for 5 mins
3	1	Robot reached intended area and traveled back and forth for 5 mins
4	2	Robot reached intended area and traveled back and forth for 5 mins

- **Conclusions:** All four trials were successful from all corners. Team 9 assisted in trials 2 and 3 by having their robot take a shot at the goal behind d1 = 8. The robot was able to block both shots while successfully staying within the allowed region. No changes need to be made to the defense code.

9 GLOSSARY OF TERMS

- Requirements document: Separate document in which the requirements of the project are outlined and discussed in detail.
- Mindstorm EV3 kit: This is the hardware kit containing the majority of the hardware components to be used in this project.
- API: The Application program interface is a set of routines, protocols, and tools for building software applications
- Java Lejos API: The firmware used in order to allow Java code to be executed on the Mindstorm EV3 device.
- Noise: unwanted data reported by devices that causes error in performance
- Mean: The Mean is: $\mu = \frac{1}{N}\sum_{i=1}^{N} \Delta X$;
  Where:
  - N: number of trials
  - X: data sample
- Standard Deviation: $\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$;