

# Scientific Experimentation and Evaluation

## - Assignment 02 -

### Experiment Report

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April 18, 2016

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## 1 ABSTRACT

This report describes the performance of some experiments to measure the motion of a Lego robot. It describes the robot used, the measurement process, the performance of the experiment and its results.

## 2 THE ROBOT'S DESIGN

Our robot is the 5-minutes bot from the official Lego website with some additions made (see figure 2.1). It has the standard two actuated wheels to the left and the right of the robot and one fixed non-actuated wheel in the back. The actuated wheels have a diameter of 5.6cm and are each about 8.5cm displaced with respect to the center. Right next to its actuated wheels are two markers close to the ground aligned with the wheel axis to be used to measure the position of the robot.



(a) Front View



(b) Side View



(c) Top View

Figure 2.1: Images of the robot

### 3 THE MEASUREMENT PROCESS

On our measurement facility we mark the starting positions of the two markers on the ground and define the position of the right marker as the origin of our grid. The y-axis points in the direction the robot is facing and the x-axis to the right. The experiments consists of three parts:

- Driving forward
- Right Arc
- Left Arc

Before performing the drive command, we place the robot in the start position and manually align its markers with the marks on the ground. After performing the drive command we press the markers down so they touch the ground and mark their positions with a sharpened pencil. We then use rulers to measure the positions of the marks with respect to the origin of our system. After each run we erase all but the start markers and place the robot back at the start position. We repeat this 20 times for each experiment. During all the experiments the robot is plugged to the power source.

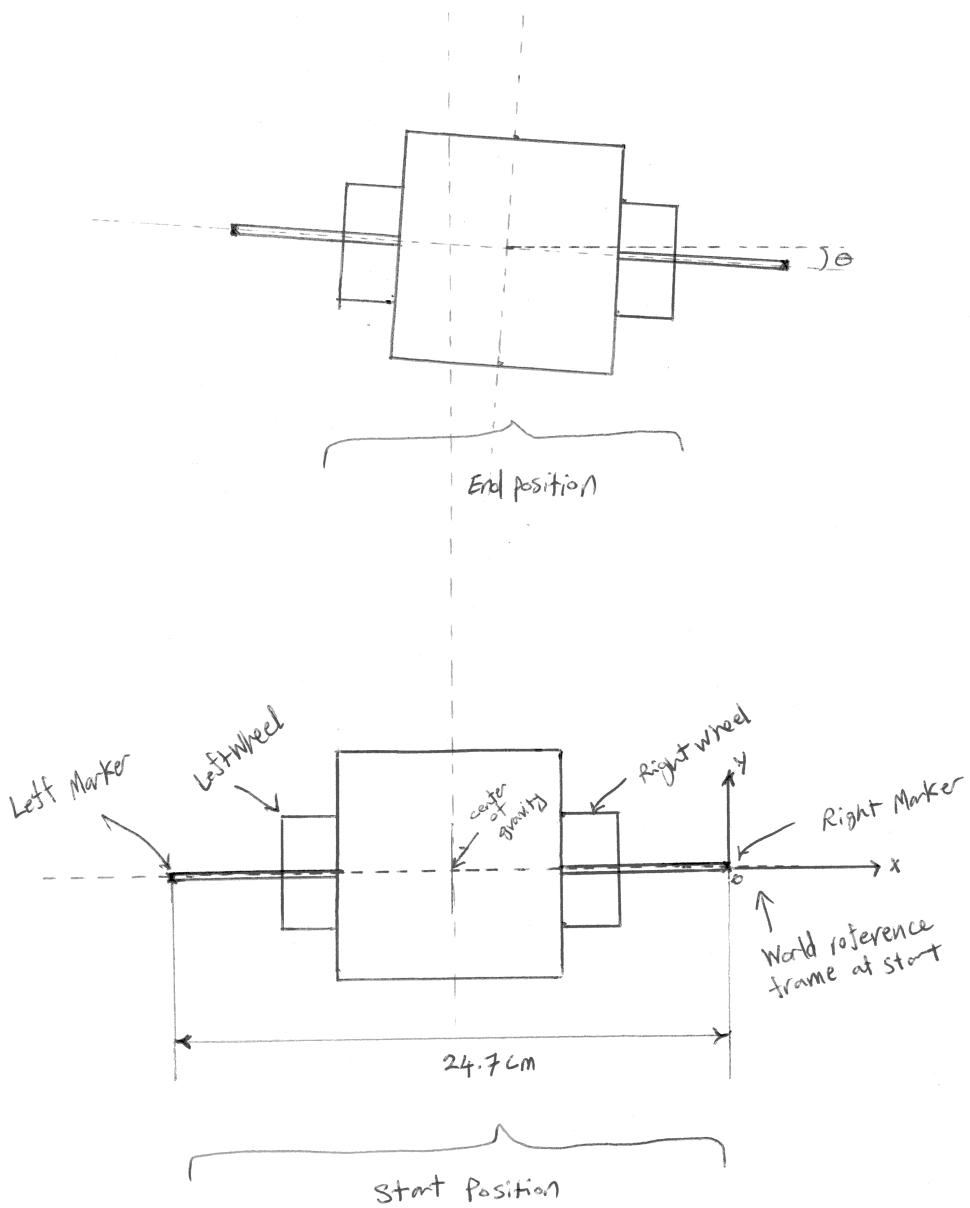
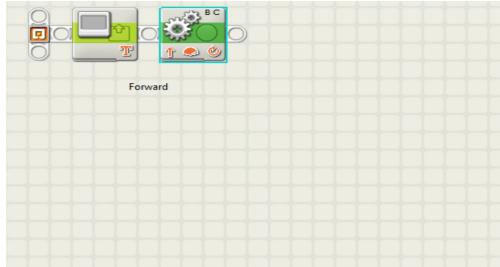


Figure 3.1: Sketch of Experiment Performance

## 4 EXPERIMENT

We tested three different scenarios for driving the robot. The first was to let the robot drive forward by letting the wheels do 1.5 rotations with full power. The second was driving in a right arc by commanding the left wheel to do 2 rotations with full power and the right wheel to do 1 rotation with half power. The last scenario was driving in a left arc by rotating the left

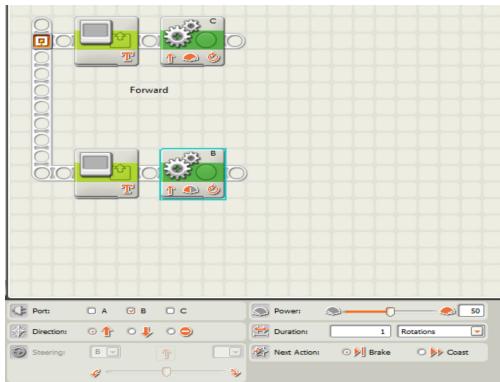
wheel once with half power and the right wheel twice with full power. The programs created in Lego's visual IDE can be seen in figure 4.1



(a) Program for forward motion



(b) Program for Right Arc



(c) Program for Left Arc

Figure 4.1: Programs used for the experiments in Lego's visual IDE

## 5 RESULTS

The results of the experiments can be seen in the appendix (Section 7).

### 5.1 FORWARD

Given a straight movement with 5.6cm wheel diameter and 1.5 rotations we would expect a travelled distance of about 26.4cm. The average in our experiments is 24.8cm for the left wheel and 24.0 for the right wheel. The final orientation was tilted by minus two degrees in average with a standard deviation of 2 degrees.

### 5.2 RIGHT ARC

For the right arc the left wheel's final position was in average (-8.4|32.0) with a standard deviation of (0.5cm|0.2cm). The right wheel's final position was (5.2|11.4) in average with a

standard deviation of (0.3cm|0.3cm). The final orientation was -56 degrees in average with a standard deviation of 1.

### 5.3 LEFT ARC

For the right arc the left wheel's final position was in average (-30.8|11.5) with a standard deviation of (0.1cm|0.2cm). The right wheel's final position was (-16.1|31.5) in average with a standard deviation of (0.3cm|0.2cm). The final orientation was 54 degrees in average with a standard deviation of 1.

## 6 CONCLUSION

For the straight forward experiment we expected more travelled distance and no tilting in the end, but the robot was slightly tilted to the right in average. For the arc-experiments we expected a similar, but negated result than the opposite movement. But it turned out that the robot was turning slightly more to the right than to the left. Overall we could observe a small bias to the right.

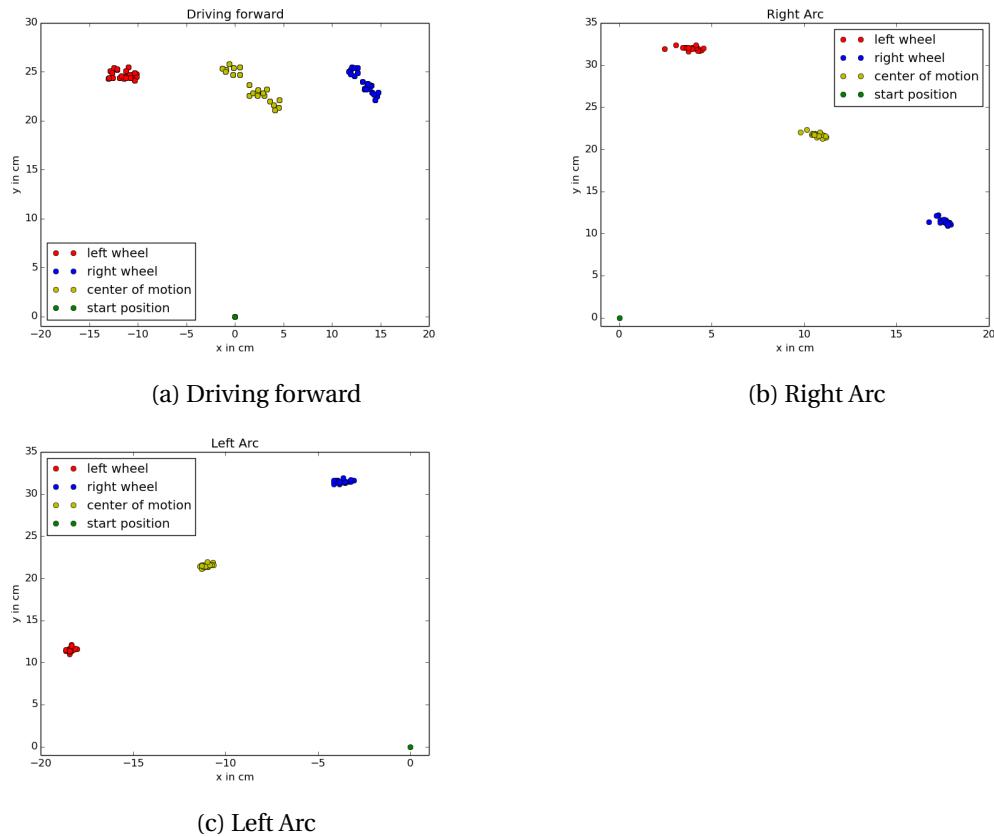


Figure 6.1: Plots of robot's end positions

## 7 APPENDIX

| Starting parameters      |       |      |             |      |                  |       |                   |       |       |         |         |
|--------------------------|-------|------|-------------|------|------------------|-------|-------------------|-------|-------|---------|---------|
|                          | Left  |      | Right       |      |                  |       |                   |       |       |         |         |
|                          | x     | y    | x           | y    |                  |       |                   |       |       |         |         |
| Marker                   | -24.7 | 0.0  | 0.0         | 0.0  |                  |       |                   |       |       |         |         |
| Wheel Diameter           | 5.6   |      |             |      |                  |       |                   |       |       |         |         |
| Straight Line Experiment |       |      | Revolutions | 1.5  | Travled distance | 24.6  |                   |       |       |         |         |
|                          | Left  |      | Right       |      | Validation       |       | Center of Gravity |       | Theta |         |         |
|                          | x     | y    | x           | y    | xr - xl          | yr-yl | L                 | x     | y     | Radians | Degrees |
| 1                        | -22.5 | 24.8 | 2.3         | 22.5 | 24.8             | -2.3  | 24.9              | -10.1 | 23.7  | -0.09   | -5      |
| 2                        | -22.9 | 24.7 | 1.8         | 22.9 | 24.7             | -1.8  | 24.8              | -10.6 | 23.8  | -0.07   | -4      |
| 3                        | -25.2 | 25.1 | -0.4        | 25.2 | 24.8             | 0.1   | 24.8              | -12.8 | 25.2  | 0.00    | 0       |
| 4                        | -24.5 | 25.2 | 0.3         | 25.4 | 24.8             | 0.2   | 24.8              | -12.1 | 25.3  | 0.01    | 0       |
| 5                        | -25.0 | 24.9 | -0.3        | 25.5 | 24.7             | 0.6   | 24.7              | -12.7 | 25.2  | 0.02    | 1       |
| 6                        | -24.8 | 25.4 | 0.0         | 25.4 | 24.8             | 0.0   | 24.8              | -12.4 | 25.4  | 0.00    | 0       |
| 7                        | -23.2 | 24.7 | 1.5         | 23.3 | 24.7             | -1.4  | 24.7              | -10.9 | 24.0  | -0.06   | -3      |
| 8                        | -23.8 | 24.3 | 1.0         | 23.3 | 24.8             | -1.0  | 24.8              | -11.4 | 23.8  | -0.04   | -2      |
| 9                        | -23.1 | 24.4 | 1.7         | 23.6 | 24.8             | -0.8  | 24.8              | -10.7 | 24.0  | -0.03   | -2      |
| 10                       | -22.7 | 24.1 | 2.1         | 22.1 | 24.8             | -2.0  | 24.9              | -10.3 | 23.1  | -0.08   | -5      |
| 11                       | -23.6 | 24.5 | 1.2         | 23.4 | 24.8             | -1.1  | 24.8              | -11.2 | 24.0  | -0.04   | -3      |
| 12                       | -24.9 | 24.4 | 0.0         | 24.6 | 24.9             | 0.2   | 24.9              | -12.5 | 24.5  | 0.01    | 0       |
| 13                       | -23.3 | 25.5 | 1.5         | 23.7 | 24.8             | -1.8  | 24.9              | -10.9 | 24.6  | -0.07   | -4      |
| 14                       | -24.0 | 24.6 | 0.8         | 24.0 | 24.8             | -0.6  | 24.8              | -11.6 | 24.3  | -0.02   | -1      |
| 15                       | -23.6 | 24.4 | 1.2         | 23.2 | 24.8             | -1.2  | 24.8              | -11.2 | 23.8  | -0.05   | -3      |
| 16                       | -23.6 | 25.1 | 1.3         | 23.8 | 24.9             | -1.3  | 24.9              | -11.2 | 24.5  | -0.05   | -3      |
| 17                       | -25.4 | 24.3 | -0.6        | 25.0 | 24.8             | 0.7   | 24.8              | -13.0 | 24.7  | 0.03    | 2       |
| 18                       | -22.7 | 24.9 | 2.0         | 22.7 | 24.7             | -2.2  | 24.8              | -10.4 | 23.8  | -0.09   | -5      |
| 19                       | -25.3 | 24.4 | -0.4        | 24.8 | 24.9             | 0.4   | 24.9              | -12.9 | 24.6  | 0.02    | 1       |
| 20                       | -24.5 | 25.3 | 0.3         | 24.9 | 24.8             | -0.4  | 24.8              | -12.1 | 25.1  | -0.02   | -1      |
| Average                  | -23.9 | 24.8 | 0.9         | 24.0 | 24.8             | -0.8  | 24.8              | -11.5 | 24.4  | -0.03   | -2      |
| Standard Dev.            | 0.9   | 0.4  | 0.9         | 1.0  | 0.1              | 0.9   | 0.1               | 0.9   | 0.6   | 0.04    | 2       |
| Right Arc Experiment     |       |      |             |      |                  |       |                   |       |       |         |         |
|                          | Left  |      | Right       |      | Validation       |       | Center of Gravity |       | Theta |         |         |
|                          | x     | y    | x           | y    | xr - xl          | yr-yl | L                 | x     | y     | Radians | Degrees |
| 1                        | -8.3  | 32.1 | 4.4         | 11.4 | 12.7             | -20.7 | 24.3              | -2.0  | 21.8  | -1.02   | -58     |
| 2                        | -8.6  | 31.6 | 5.3         | 11.2 | 13.9             | -20.4 | 24.7              | -1.7  | 21.4  | -0.97   | -56     |

| 3                          | -9.3  | 32.4 | 4.9   | 12.2 | 14.2       | -20.2   | 24.7 | -2.2              | 22.3 | -0.96   | -55     |
|----------------------------|-------|------|-------|------|------------|---------|------|-------------------|------|---------|---------|
| 4                          | -8.8  | 32.1 | 5.3   | 11.6 | 14.1       | -20.5   | 24.9 | -1.8              | 21.9 | -0.97   | -55     |
| 5                          | -8.9  | 32.1 | 5.1   | 11.6 | 14.0       | -20.5   | 24.8 | -1.9              | 21.9 | -0.97   | -56     |
| 6                          | -8.2  | 31.9 | 5.5   | 11.2 | 13.7       | -20.7   | 24.8 | -1.4              | 21.6 | -0.99   | -57     |
| 7                          | -8.0  | 31.7 | 5.4   | 11.0 | 13.4       | -20.7   | 24.7 | -1.3              | 21.4 | -1.00   | -57     |
| 8                          | -7.9  | 31.8 | 5.6   | 11.1 | 13.5       | -20.7   | 24.7 | -1.2              | 21.5 | -0.99   | -57     |
| 9                          | -9.9  | 31.9 | 4.8   | 12.1 | 14.7       | -19.8   | 24.7 | -2.6              | 22.0 | -0.93   | -53     |
| 10                         | -8.1  | 32.0 | 5.5   | 11.3 | 13.6       | -20.7   | 24.8 | -1.3              | 21.7 | -0.99   | -57     |
| 11                         | -8.7  | 32.1 | 5.0   | 11.6 | 13.7       | -20.5   | 24.7 | -1.9              | 21.9 | -0.98   | -56     |
| 12                         | -8.2  | 32.1 | 5.3   | 11.4 | 13.5       | -20.7   | 24.7 | -1.5              | 21.8 | -0.99   | -57     |
| 13                         | -8.2  | 32.1 | 5.4   | 11.3 | 13.6       | -20.8   | 24.9 | -1.4              | 21.7 | -0.99   | -57     |
| 14                         | -8.1  | 31.7 | 5.4   | 10.9 | 13.5       | -20.8   | 24.8 | -1.4              | 21.3 | -1.00   | -57     |
| 15                         | -8.2  | 32.1 | 5.4   | 11.4 | 13.6       | -20.7   | 24.8 | -1.4              | 21.8 | -0.99   | -57     |
| 16                         | -8.4  | 32.1 | 5.2   | 11.4 | 13.6       | -20.7   | 24.8 | -1.6              | 21.8 | -0.99   | -57     |
| 17                         | -8.2  | 32.4 | 5.2   | 11.7 | 13.4       | -20.7   | 24.7 | -1.5              | 22.1 | -1.00   | -57     |
| 18                         | -8.4  | 31.9 | 5.3   | 11.3 | 13.7       | -20.6   | 24.7 | -1.6              | 21.6 | -0.98   | -56     |
| 19                         | -8.6  | 32.1 | 5.0   | 11.3 | 13.6       | -20.8   | 24.9 | -1.8              | 21.7 | -0.99   | -57     |
| 20                         | -7.8  | 32.0 | 5.4   | 11.1 | 13.2       | -20.9   | 24.7 | -1.2              | 21.6 | -1.01   | -58     |
| Average                    | -8.4  | 32.0 | 5.2   | 11.4 | 13.7       | -20.6   | 24.7 | -1.6              | 21.7 | -0.99   | -56     |
| Standard Dev.              | 0.5   | 0.2  | 0.3   | 0.3  | 0.4        | 0.2     | 0.1  | 0.3               | 0.2  | 0.02    | 1       |
| <b>Left Arc Experiment</b> |       |      |       |      |            |         |      |                   |      |         |         |
|                            | Left  |      | Right |      | Validation |         |      | Center of Gravity |      | Theta   |         |
|                            | x     | y    | x     | y    | xr - xl    | yr - yl | L    | x                 | y    | Radians | Degrees |
| 1                          | -30.7 | 12.1 | -15.4 | 31.6 | 15.3       | 19.5    | 24.8 | -23.1             | 21.9 | 0.91    | 52      |
| 2                          | -30.8 | 11.7 | -15.9 | 31.5 | 14.9       | 19.8    | 24.8 | -23.4             | 21.6 | 0.93    | 53      |
| 3                          | -30.9 | 11.5 | -16.1 | 31.4 | 14.8       | 19.9    | 24.8 | -23.5             | 21.5 | 0.93    | 53      |
| 4                          | -30.6 | 11.7 | -15.7 | 31.5 | 14.9       | 19.8    | 24.8 | -23.2             | 21.6 | 0.93    | 53      |
| 5                          | -30.9 | 11.4 | -16.2 | 31.2 | 14.7       | 19.8    | 24.7 | -23.6             | 21.3 | 0.93    | 53      |
| 6                          | -31.0 | 11.4 | -16.5 | 31.5 | 14.5       | 20.1    | 24.8 | -23.8             | 21.5 | 0.95    | 54      |
| 7                          | -30.8 | 11.5 | -16.3 | 31.6 | 14.5       | 20.1    | 24.8 | -23.6             | 21.6 | 0.95    | 54      |
| 8                          | -30.7 | 11.4 | -15.9 | 31.3 | 14.8       | 19.9    | 24.8 | -23.3             | 21.4 | 0.93    | 53      |
| 9                          | -30.7 | 11.4 | -16.1 | 31.4 | 14.6       | 20.0    | 24.8 | -23.4             | 21.4 | 0.94    | 54      |
| 10                         | -31.0 | 11.5 | -16.3 | 31.6 | 14.7       | 20.1    | 24.9 | -23.7             | 21.6 | 0.94    | 54      |
| 11                         | -30.8 | 11.0 | -16.5 | 31.2 | 14.3       | 20.2    | 24.7 | -23.7             | 21.1 | 0.95    | 55      |
| 12                         | -30.8 | 11.5 | -15.9 | 31.4 | 14.9       | 19.9    | 24.9 | -23.4             | 21.5 | 0.93    | 53      |

|               |       |      |       |      |      |      |      |       |      |      |    |
|---------------|-------|------|-------|------|------|------|------|-------|------|------|----|
| 13            | -30.8 | 11.4 | -16.4 | 31.6 | 14.4 | 20.2 | 24.8 | -23.6 | 21.5 | 0.95 | 55 |
| 14            | -30.4 | 11.6 | -15.6 | 31.5 | 14.8 | 19.9 | 24.8 | -23.0 | 21.6 | 0.93 | 53 |
| 15            | -30.8 | 11.3 | -16.3 | 31.4 | 14.5 | 20.1 | 24.8 | -23.6 | 21.4 | 0.95 | 54 |
| 16            | -30.7 | 11.4 | -16.2 | 31.5 | 14.5 | 20.1 | 24.8 | -23.5 | 21.5 | 0.95 | 54 |
| 17            | -30.6 | 11.5 | -15.6 | 31.7 | 15.0 | 20.2 | 25.2 | -23.1 | 21.6 | 0.93 | 53 |
| 18            | -30.8 | 11.4 | -16.5 | 31.6 | 14.3 | 20.2 | 24.7 | -23.7 | 21.5 | 0.95 | 55 |
| 19            | -30.5 | 11.7 | -15.9 | 31.5 | 14.6 | 19.8 | 24.6 | -23.2 | 21.6 | 0.94 | 54 |
| 20            | -30.7 | 12.0 | -16.0 | 31.9 | 14.7 | 19.9 | 24.7 | -23.4 | 22.0 | 0.93 | 54 |
| Average       | -30.8 | 11.5 | -16.1 | 31.5 | 14.7 | 20.0 | 24.8 | -23.4 | 21.5 | 0.94 | 54 |
| Standard Dev. | 0.1   | 0.2  | 0.3   | 0.2  | 0.2  | 0.2  | 0.1  | 0.2   | 0.2  | 0.01 | 1  |