

# Lab Report of Research Track 2 - Assignment 3

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**Abstract**—This study investigates the impact of bot velocity on reliability, defined as the consistency in performing tasks across various environments. The **Null Hypothesis (H0)** posits that bot reliability is independent of velocity, while the **Alternative Hypothesis (H1)** suggests that reliability is influenced by velocity. Two bots were tested in three environments: 6 tokens in a circle, 8 tokens in a circle, and 6 tokens placed randomly, with each bot undergoing 15 tests per environment. Results indicate significant differences in bot performance, providing insights into how velocity affects reliability and guiding future bot design optimizations.

**Keywords**—velocity, reliability, statistics, t-test

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## 1. Hypotheses made

**Null hypothesis (H0):** The reliability of the bots is not affected by their velocity.

**Alternative Hypothesis (H1):** The reliability of the bots is influenced by their velocity.

## 2. Description and motivation of the experimental setup

The motivation behind the experiment is to assess whether the velocity of the bots has any impact on their reliability. By testing them in three different environments with varying numbers and configurations of tokens, we aim to provide a comprehensive understanding of how the bot's performance is affected by their speed.

In each environment:

- 6 tokens in a circle<sup>1</sup>: This environment represents a simple, structured layout.
- 8 tokens in a circle<sup>2</sup>: This environment introduces a higher token density, challenging the bots' navigation abilities.
- 6 tokens placed randomly<sup>3</sup>: This environment simulates unpredictable conditions, requiring adaptability from the bots.

Each bot will undergo 15 tests in each environment, allowing for a thorough evaluation of their reliability across different scenarios. The results of these tests will provide valuable insights into the relationship between bot velocity and reliability, aiding in the optimization of future bot designs and applications.

## 2.1. Figures

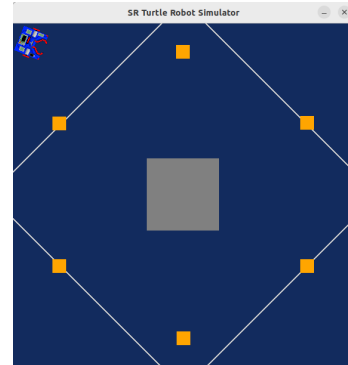


Figure 1. Environment 1: 6 tokens placed in circle.

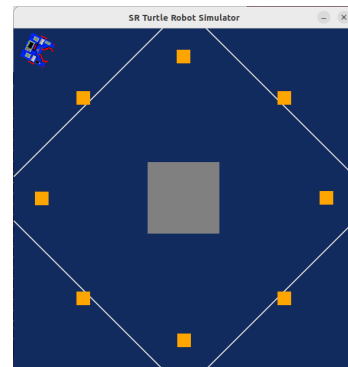


Figure 2. Environment 2: 8 tokens placed in circle.



Figure 3. Environment 3: 6 tokens placed randomly. (Every time the code is executed, the placement is changed.)

## 2.2. Formulas Used

### 2.2.1. Normalization

The formula (1) shows how to normalize a value  $x$ :

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (1)$$

where:

- $x$  is the original value,
- $x'$  is the normalized value,
- $\min(x)$  is the minimum value in the dataset,
- $\max(x)$  is the maximum value in the dataset.

### 2.2.2. Mean

The mean (average) of a set of values  $x_1, x_2, \dots, x_n$  is the sum of the values divided by the number of values:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (2)$$

where  $\bar{x}$  is the mean,  $n$  is the number of values, and  $x_i$  represents each value.

### 2.2.3. Standard Deviation

The standard deviation is a measure of the amount of variation or dispersion in a set of values:

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (3)$$

where  $\sigma$  is the standard deviation,  $n$  is the number of values,  $x_i$  represents each value, and  $\bar{x}$  is the mean.

### T-Test for Paired Samples

For paired samples  $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$ :

#### 2.2.4. Mean Difference

The mean difference is the average of the differences between each pair of values:

$$\bar{d} = \frac{1}{n} \sum_{i=1}^n (x_i - y_i) \quad (4)$$

where  $\bar{d}$  is the mean difference and  $d_i = x_i - y_i$  is the difference for each pair.

#### 2.2.5. Standard Deviation of Differences

The standard deviation of the differences is calculated as:

$$s_d = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (d_i - \bar{d})^2} \quad (5)$$

where  $s_d$  is the standard deviation of the differences,  $d_i$  is each difference, and  $\bar{d}$  is the mean difference.

#### 2.2.6. T-Statistic

The t-statistic for the paired samples t-test is calculated as:

$$t = \frac{\bar{d}}{s_d / \sqrt{n}} \quad (6)$$

where  $t$  is the t-statistic,  $\bar{d}$  is the mean difference,  $s_d$  is the standard deviation of the differences, and  $n$  is the number of pairs.

#### 2.2.7. Degrees of Freedom

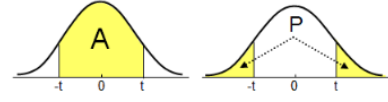
The degrees of freedom for the paired samples t-test is given by:

$$df = n - 1 \quad (7)$$

where  $df$  is the degrees of freedom and  $n$  is the number of pairs.

#### 2.2.8. Critical Value and P-Value

The critical value for a given confidence level and degrees of freedom can be found using the t-distribution table. The p-value indicates the probability of obtaining a result at least as extreme as the one observed, under the assumption that the null hypothesis is true.



| DF | A<br>P | 0.80<br>0.20 | 0.90<br>0.10 | 0.95<br>0.05 | 0.98<br>0.02 | 0.99<br>0.01 | 0.995<br>0.005 | 0.998<br>0.002 | 0.999<br>0.001 |
|----|--------|--------------|--------------|--------------|--------------|--------------|----------------|----------------|----------------|
| 1  |        | 3.078        | 6.314        | 12.706       | 31.820       | 63.657       | 127.321        | 318.309        | 636.619        |
| 2  |        | 1.886        | 2.920        | 4.303        | 6.965        | 9.925        | 14.089         | 22.327         | 31.599         |
| 3  |        | 1.638        | 2.353        | 3.182        | 4.541        | 5.841        | 7.453          | 10.215         | 12.924         |
| 4  |        | 1.533        | 2.132        | 2.776        | 3.747        | 4.604        | 5.598          | 7.173          | 8.610          |
| 5  |        | 1.476        | 2.015        | 2.571        | 3.365        | 4.032        | 4.773          | 5.893          | 6.869          |
| 6  |        | 1.440        | 1.943        | 2.447        | 3.143        | 3.707        | 4.317          | 5.208          | 5.959          |
| 7  |        | 1.415        | 1.895        | 2.365        | 2.998        | 3.499        | 4.029          | 4.785          | 5.408          |
| 8  |        | 1.397        | 1.860        | 2.306        | 2.897        | 3.355        | 3.833          | 4.501          | 5.041          |
| 9  |        | 1.383        | 1.833        | 2.262        | 2.821        | 3.250        | 3.690          | 4.297          | 4.781          |
| 10 |        | 1.372        | 1.812        | 2.228        | 2.764        | 3.169        | 3.581          | 4.144          | 4.587          |
| 11 |        | 1.363        | 1.796        | 2.201        | 2.718        | 3.106        | 3.497          | 4.025          | 4.437          |
| 12 |        | 1.356        | 1.782        | 2.179        | 2.681        | 3.055        | 3.428          | 3.930          | 4.318          |
| 13 |        | 1.350        | 1.771        | 2.160        | 2.650        | 3.012        | 3.372          | 3.852          | 4.221          |
| 14 |        | 1.345        | 1.761        | 2.145        | 2.625        | 2.977        | 3.326          | 3.787          | 4.140          |
| 15 |        | 1.341        | 1.753        | 2.131        | 2.602        | 2.947        | 3.286          | 3.733          | 4.073          |

Figure 4. T-Distribution Table.

### 2.2.9. Pearson Correlation Coefficient

The Pearson correlation coefficient  $r$  measures the strength and direction of the linear relationship between two variables:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (8)$$

where  $r$  is the Pearson correlation coefficient,  $x_i$  and  $y_i$  are the individual sample points, and  $\bar{x}$  and  $\bar{y}$  are the means of the  $x$  and  $y$  values, respectively.

## 3. Results

### 3.1. Environment 1

| n  | Execution Time |               |               |               |
|----|----------------|---------------|---------------|---------------|
|    | Bot 1<br>Time  | Bot 1<br>Norm | Bot 2<br>Time | Bot 2<br>Norm |
| 1  | 54,95987       | 0,37264       | 84,65280      | 0,42076       |
| 2  | 55,27446       | 0,41775       | 85,44914      | 1,00000       |
| 3  | 52,36114       | 0,00000       | 84,46955      | 0,28746       |
| 4  | 54,49469       | 0,30594       | 85,05623      | 0,71420       |
| 5  | 53,37611       | 0,14554       | 85,26286      | 0,86450       |
| 6  | 54,61364       | 0,32300       | 85,14409      | 0,77811       |
| 7  | 58,05734       | 0,81680       | 84,78617      | 0,51777       |
| 8  | 59,33492       | 1,00000       | 84,36953      | 0,21471       |
| 9  | 55,13069       | 0,39714       | 85,04686      | 0,70739       |
| 10 | 59,19231       | 0,97955       | 84,77364      | 0,50865       |
| 11 | 55,94048       | 0,51326       | 84,87707      | 0,58389       |
| 12 | 55,06786       | 0,38813       | 84,82687      | 0,54737       |
| 13 | 54,45313       | 0,29998       | 84,47823      | 0,29378       |
| 14 | 55,04985       | 0,38555       | 84,07435      | 0,00000       |
| 15 | 54,39741       | 0,29199       | 84,99850      | 0,67221       |

Table 1. Environment 1 - 6 tokens circle

### 3.2. Environment 2

| Execution Time |            |            |            |            |
|----------------|------------|------------|------------|------------|
| n              | Bot 1 Time | Bot 1 Norm | Bot 2 Time | Bot 2 Norm |
| 1              | 78,26205   | 0,88435    | 116,657028 | 0,47663    |
| 2              | 75,80831   | 0,61791    | 116,31924  | 0,42759    |
| 3              | 75,55868   | 0,59081    | 116,99526  | 0,52573    |
| 4              | 78,65301   | 0,92680    | 116,06432  | 0,39058    |
| 5              | 72,04576   | 0,20935    | 118,91829  | 0,80490    |
| 6              | 77,80490   | 0,83471    | 115,75485  | 0,34566    |
| 7              | 76,69070   | 0,71373    | 116,05548  | 0,38930    |
| 8              | 74,82334   | 0,51096    | 114,75795  | 0,20094    |
| 9              | 74,27251   | 0,45115    | 113,37381  | 0,00000    |
| 10             | 70,11775   | 0,00000    | 116,49312  | 0,45283    |
| 11             | 74,89910   | 0,51918    | 116,00306  | 0,38169    |
| 12             | 76,60168   | 0,70406    | 119,4113   | 0,87647    |
| 13             | 79,25859   | 0,99256    | 116,68213  | 0,48027    |
| 14             | 79,32709   | 1,00000    | 120,26223  | 1,00000    |
| 15             | 78,25032   | 0,88308    | 116,50902  | 0,45514    |

Table 2. Environment 2 - 8 tokens circle

### 3.3. Environment 3

| Execution Time |            |            |            |            |
|----------------|------------|------------|------------|------------|
| n              | Bot 1 Time | Bot 1 Norm | Bot 2 Time | Bot 2 Norm |
| 1              | 40,401829  | 0,01667    | 84,97362   | 0,46923    |
| 2              | 135,85114  | 0,96113    | 85,44431   | 0,47718    |
| 3              | 45,36058   | 0,06574    | 85,65030   | 0,48065    |
| 4              | 42,24703   | 0,03493    | 57,17782   | 0,00000    |
| 5              | 48,69830   | 0,09876    | 87,33356   | 0,50907    |
| 6              | 52,72143   | 0,13857    | 86,11785   | 0,48855    |
| 7              | 49,40143   | 0,10572    | 85,95040   | 0,48572    |
| 8              | 60,81553   | 0,21866    | 116,41468  | 1,00000    |
| 9              | 113,40459  | 0,73903    | 107,32852  | 0,84661    |
| 10             | 42,96383   | 0,04202    | 86,54248   | 0,49572    |
| 11             | 46,06564   | 0,07271    | 87,01203   | 0,50364    |
| 12             | 53,95710   | 0,15080    | 96,37539   | 0,66171    |
| 13             | 139,77931  | 1,00000    | 73,42112   | 0,27421    |
| 14             | 55,21156   | 0,16321    | 61,83233   | 0,07857    |
| 15             | 38,71700   | 0,00000    | 90,46885   | 0,56200    |

Table 3. Environment 3 - 6 tokens random

## 4. Discussion of the results with statistical analysis

### Environment 1: 6 Tokens in a Circle

#### • Bot 1:

- Mean: 55.447
- Normalized Mean: 0,442
- Standard Deviation: 1.904
- Normalized Standard Deviation: 0,273

#### • Bot 2:

- Mean: 84.818
- Normalized Mean: 0,541
- Standard Deviation: 0.353
- Normalized Standard Deviation: 0,257

#### • t-Test: Paired Two Sample for Means

- Mean Difference: 0.447
- Variance Difference: 0.086

- Observations: 15
- Pearson Correlation: -0.206
- Degrees of Freedom: 14
- t Stat: -0.866
- P(T<=t) two-tail: 0.401
- t Critical two-tail: 2.145

### Environment 2: 8 Tokens in a Circle

#### • Bot 1:

- Mean: 76.158
- Normalized Mean: 0,656
- Standard Deviation: 2.565
- Normalized Standard Deviation: 0,279

#### • Bot 2:

- Mean: 116.684
- Normalized Mean: 0,481
- Standard Deviation: 1.679
- Normalized Standard Deviation: 0,244

#### • t-Test: Paired Two Sample for Means

- Mean Difference: 0.640
- Variance Difference: 0.085
- Observations: 15
- Pearson Correlation: 0.164
- Degrees of Freedom: 14
- t Stat: 1.656
- P(T<=t) two-tail: 0.120
- t Critical two-tail: 2.145

### Environment 3: 6 Tokens Placed Randomly

#### • Bot 1:

- Mean: 64.373
- Normalized Mean: 0,254
- Standard Deviation: 33.553
- Normalized Standard Deviation: 0,332

#### • Bot 2:

- Mean: 86.136
- Normalized Mean: 0,489
- Standard Deviation: 14.341
- Normalized Standard Deviation: 0,242

#### • t-Test: Paired Two Sample for Means

- Mean Difference: 0.271
- Variance Difference: 0.123
- Observations: 15
- Pearson Correlation: 0.076
- Degrees of Freedom: 14
- t Stat: -1.955
- P(T<=t) two-tail: 0.071
- t Critical two-tail: 2.145

## 5. Contact us

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