ECE 3 Lab 1-F

# Final Project Report


Anmol Gupta (005-723-941)

Sujay Jain (805-572-165)

**Introduction**

This project aimed to code a line-following car on a Texas Instrument's Robotic System Learning Kit (TI-RSLK) using a closed-loop control system (PD) to enable the car to follow the given track, including navigating curves and making a donut turn in under 20 seconds. The following report only documents the on-track path-following testing of our car.

Before discussing the testing of our project, it is helpful to note a few design choices that we made while writing the code. A commented copy of our code can be viewed here. We employed a proportional constant Kp to respond to the current error term and a derivative constant Kd to prevent over-correction and increase stability. Next, we used the Encoder Count to map the entire track into different sections where we could have different values for the base speed, Kp, and Kd terms. Finally, we utilized a sum of the raw IR sensor values to determine when the car should make a donut turn or stop. It is also important to note that the (8-4-2-1-1-2-4-8) weighting scheme was used to fuse normalized sensor values and was controlled throughout our testing.

**Conducting Tests**

We tested the car on the track in the ECE 3 lab by measuring and changing the following variables: Kp, Kd, and base speed. We also measured but did not control the right wheel's Encoder Count and used it to define different sections of the track. We used different values for Kp, Kd, and base speed in each section based on its curvature to maximize the speed we could achieve. A complete log of all our test data can be found here.

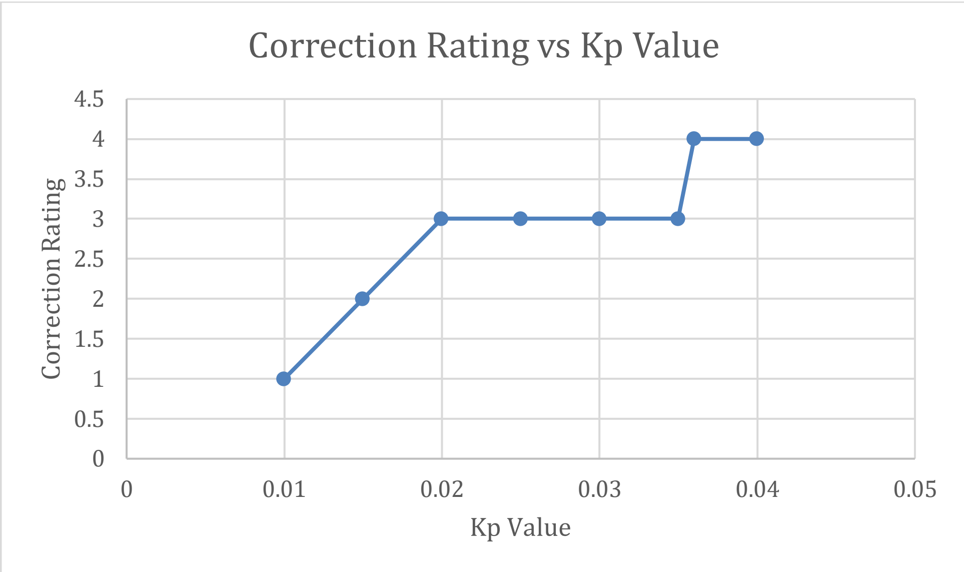
**Analysis**

We analyzed the data from our test runs to change Kp, Kd, and base speeds for different track sections. We only changed one of the three variables for any given test run. Below are two tables and graphs that show how we picked the Kp and Kd for a base speed of 170 for the large straight segment of the track.

**Kp vs. Course Correction Rating**

| Kp | Correction Rating |
|---|---|
| 0.010 | 1 |
| 0.015 | 2 |
| 0.020 | 3 |
| 0.025 | 3 |
| 0.030 | 3 |
| 0.035 | 3 |
| 0.036 | 4 |
| 0.040 | 4 |

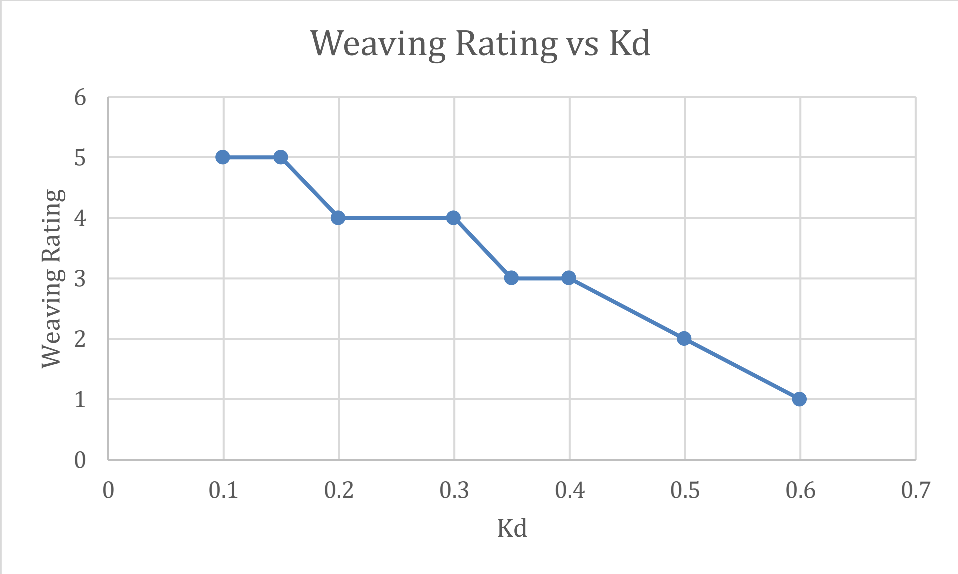
Course Correction Rating is an arbitrary criterion that we developed to assess how well the car was correcting its course quantitatively. 1 indicates that the car did not follow the track, 2 suggests the car followed the track but course correction was slow, 3 indicates the car followed the track and corrected its course quickly. Finally, 4 indicates the car followed the track but was needlessly correcting its course and causing weaving.




Kd vs. Weaving Rating

| Kd | Weaving Rating |
|---|---|
| 0.1 | 5 |
| 0.15 | 5 |
| 0.2 | 4 |
| 0.3 | 4 |
| 0.35 | 3 |
| 0.4 | 3 |
| 0.5 | 2 |
| 0.6 | 1 |

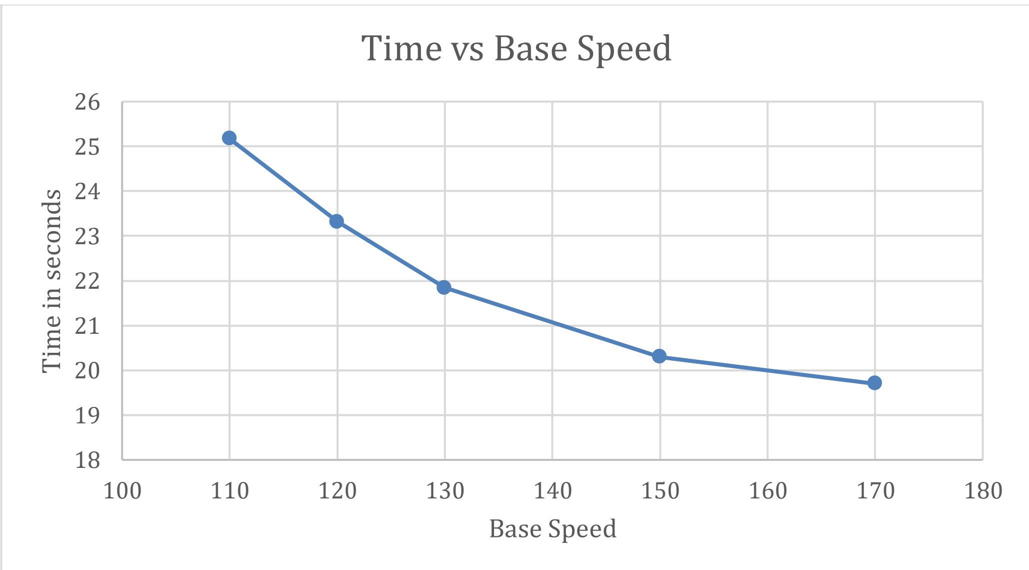
Weaving Rating is an arbitrary criterion that we developed to quantitatively assess how much the car was weaving while following the track. 1 indicates no weaving, while 5 indicates maximum weaving. Note Kp was controlled to 0.02, and base speed was 170.




Finally, we tried different base speeds and changed the Kp and Kd accordingly. The graph and table below show our results.

| Base Speed | Time | Kp | Kd |
|---|---|---|---|
| 110 | 25.17 | 0.015 | 0.035 |
| 120 | 23.32 | 0.015 | 0.35 |
| 130 | 21.84 | 0.02 | 0.35 |
| 150 | 20.3 | 0.02 | 0.45 |
| 170 | 19.7 | 0.02 | 0.6 |

The last run with base speed 170 was our final run on race day and we documented it on video which can be viewed here.



The analysis of the tests helped us figure out what to do in situations when the car could not follow the track:

1. Increase the Kp constant when it would not recognize the track and miss turns.
2. If the car was oscillating and thus wasting time, increase the Kd term.
3. Once we found a working Kp and Kd value at a certain speed, we would increase the base speed and use the same Kp and Kd, then tune from that point.

**Interpretation:**

We have analyzed the data from one particularly notable early test run to demonstrate our thought process more clearly.

| EncoderCount (x) | 0 < x ≤ 500 | 500< x ≤ 1600 | 1600 < x ≤ 3500 | 3500 t < x ≤ 11500 | 11500 < x ≤ 12500 | x >12500 |
|---|---|---|---|---|---|---|
| Speed | 120 | 55 | 150 | 100 | 55 | 110 |
| Kp | 0.03 | 0.35 | 0.02 | 0.03 | 0.02 | 0.035 |
| Kd | 0.2 | 0.15 | 0.45 | 0.3 | 0.15 | 0.10 |
| Observation | Waving a lot | Stable but a little slow. Followed the track. Not waving. | Waving a little bit but following the path. | Waving a little bit. | Stable but slow turn. Almost missed the track. Not waving. | Waved a lot. Followed track but slowed down the car. |
| Total Time | 21.8 seconds | | | | | |

From this data and the observations, we made the following deductions to reduce the time taken for the car to complete the path.

| | |
|---|---|
| 0 < x ≤ 500 | Need to increase the Kd to stabilize the car on the track. Can increase speed as well but will have to increase Kd even more to account for the increased correction due to higher base speed. |
| 500 <x ≤ 1600 | Because of the sharpness and complexity of this turn, we should only increase speed by a little bit (~5), and we need to increase Kp if we increase the speed to ensure the car follows the track. |
| 1600 < x ≤ 3500 | This is the longest straight path. Therefore, we should increase the speed significantly but also increase the Kd to prevent it from |

| | |
|---|---|
| | waving. We should increase speed by at least 10 units in the next try and increase Kd to 0.5 units. |
| 3500 < x ≤ 11500 | Since the car is waving, we should increase Kd, but the increase should be small since it's only waving a little bit. |
| 11500 < x ≤ 12500 | This is the same part of the path as 500 to 1600, but since the car is missing the track here, we should first increase the Kp and then increase the speed. Moreover, weaving in the previous section of the path may be causing the car to be more unstable and almost miss the turn in this section. |
| x >12500 | We should increase Kd to reduce the waving, and once it is stable, we should try to increase the speed here as it is the last straight path before the car comes to a complete stop. |

**Conclusion**

Based on the approach we identified just before the interpretation section, we determined whether to change Kp, Kd, or base speed while using the test data to determine how much we should change the selected value.

We also drew a couple of more common conclusions that are more broadly relevant. We deduced that we could achieve even more stability (and thus reduce the time) if we gradually sped up the car instead of making sudden changes. We also reasoned that we could have reduced our car's time to complete the path by having more precise values for the different sections of the track. Of course, the primary challenge in this endeavor would be that we have to use the Encoder Count for both wheels rather than just the right wheel as we did in our code since the encoder count for the right wheel at the first sharp curve would have measurably different values based on its starting position. Finally, we surmised that adding integral the control term Ki to further refine the car's movement could potentially allow for even more increases in speed, thereby bringing the car's time to complete the path to under 15 seconds. Nevertheless, our car completed the course in 19.7 seconds; thus, we achieved our aim.