# HW: First-Order Boustrophedon Navigator

RAS 598: Space Robotics and AI

Aman Singh Rajput
ASU ID: 1235097892

## Problem Description

The objective of this assignment is to implement and tune a PD controller in ROS2 (`turtlesim`) to execute a uniform boustrophedon (lawnmower) coverage path. The assignment involves tuning proportional and derivative gains to minimize cross-track error while following the path, and analyzing how the spacing parameter impacts coverage completeness and efficiency.

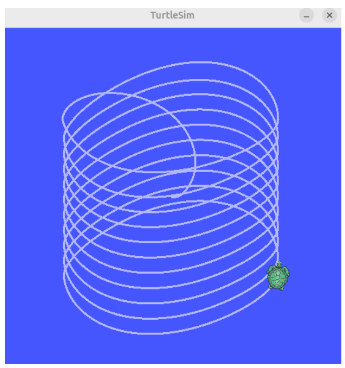


Figure 1: Path that has to be optimized by tweaking PD gains and spacing

The above image corresponds to the following parameters (example / baseline):

- **Kp linear:** 1.0
- **Kd linear:** 0.1
- **Kp angular:** 1.0
- **Kd angular:** 0.1
- **spacing:** 1.0

## Methodology

### Real-Time Tuning with RQT

- Used `rqt_plot` to visualize performance metrics such as cross-track error.
- Used `rqt_reconfigure` to modify PD gains and observe their effects in real-time.
- Observations:

- Tweaking **Kp linear**:
  - Increasing Kp linear results in faster convergence to the desired trajectory but can cause overshoot/oscillations if too high.
  - Decreasing Kp linear results in slower convergence and a less responsive system.
- Tweaking **Kd linear**:
  - Increasing Kd linear improves damping (reduces oscillation) but can slow corrections.
  - Decreasing Kd linear reduces stability and can increase oscillatory behavior.
- Tweaking **Kp angular**:
  - Increasing Kp angular improves heading correction speed but may produce sharp turns or overshoot.
  - Decreasing Kp angular yields slower angular correction and larger cross-track deviation.
- Tweaking **Kd angular**:
  - Increasing Kd angular stabilizes angular response and reduces corner overshoot.
  - Decreasing Kd angular can lead to jerky angular changes and instability.
- Adjusting **spacing**:
  - Smaller spacing improves coverage but requires tighter control and more turns.
  - Larger spacing reduces turns but may create coverage gaps.

- **Tuning approach used (trial-and-observation):**
  - Visually inspected the turtle trajectory.
  - Increased/decreased gains gradually until the lawnmower lines became uniform and cornering became clean.
  - Used cross-track error trends in `rqt_plot` to ensure error stayed small and bounded.

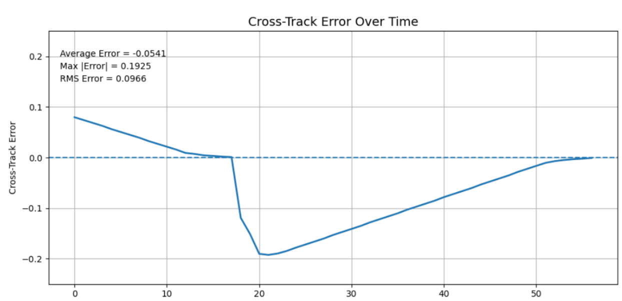


Figure 2: RQT Plot of Cross-Track Error

## Implementation

### Controller & Optimizer Updates

- The controller script were modified to improve tracking and produce a more uniform boustrophedon pattern.
- Cross-track error was monitored continuously and used as the primary tuning signal.
- The spacing parameter was adjusted to improve coverage completeness and avoid line overlap or gaps.

## Results

### Final Gains and Spacing selected

- Final tuned parameters:
  - Kp linear: 1.8
  - Kd linear: 0.25
  - Kp angular: 4.0
  - Kd angular: 0.4
  - spacing: 0.9
- Cross-track error statistics from collected samples:
  - Mean error: -0.0082
  - Mean absolute error (MAE): 0.0712
  - RMS error: 0.0872
  - Max absolute error: 0.1713
- Final tracking quality:
  - Error remained small on straight segments.
  - Peaks occurred mainly during corner transitions.
  - Overall produced a uniform lawnmower-style coverage.

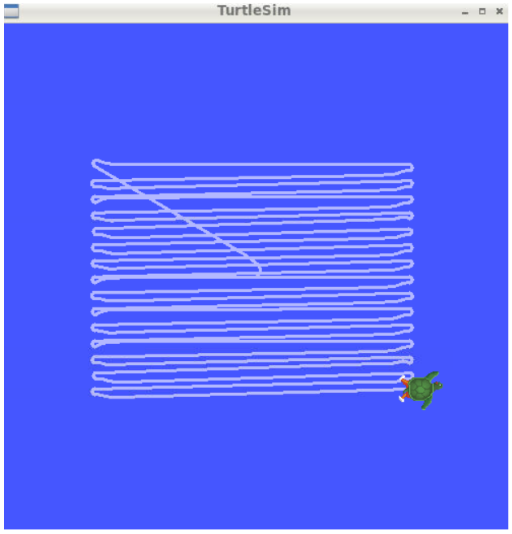


Figure 3: Resulting Trajectory with Tuned PD Gains and Spacing

## Reasoning for Spacing Selection

- The spacing value was tuned along with gains to balance coverage and stability.
- The selected spacing produced:
  - Not too close (reduced overlap / unnecessary corrections),
  - Not too far (avoided coverage gaps),
  - Uniform parallel sweep lines across the workspace.

## Performance Plots

## Challenges and Observations

- Difficulties in tuning gains manually:
  - Small changes in gains caused noticeable changes in the path and corner behavior.
  - Linear and angular gains interact; angular stability was required before linear tuning became meaningful.
- Impact of spacing on coverage:
  - Small spacing increased overlap and frequent turns.
  - Large spacing risked leaving gaps in the survey.
  - A mid-range spacing gave the best balance for uniform coverage.
- Stability vs. responsiveness trade-off:
  - High Kp improved response speed but increased oscillations.

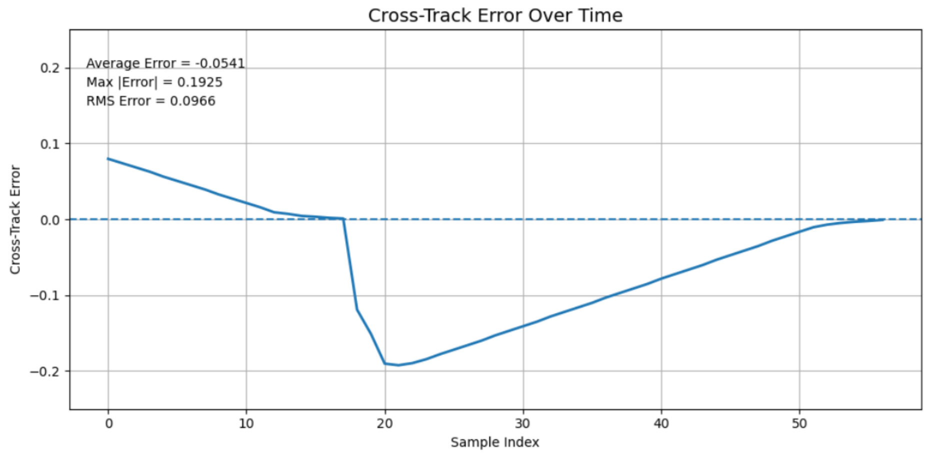


Figure 4: Cross-Track Error Over Time

  - Higher Kd reduced overshoot and stabilized the motion but could slow correction if too high.
  - Final values balanced smoothness and accuracy.

- Insights from plots:
  - Cross-track error showed periodic peaks at turns.
  - Trajectory plot confirmed uniform parallel sweeps.