Non-linear Model Predictive Control for High-speed Autonomous Racing

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The Project

This project aims at **developing algorithms** for **autonomous vehicles** able to **race at high speeds** and **avoid collisions** with obstacles in their environment. The high-speed environment poses a series of challenges including:

- High complexity of the dynamics that govern the car's behavior
- Increasing difficulty in achieving perfect localization

Motivation

This study aims at making the following contributions:

- **Increasing road safety** under high-speed conditions (emergency vehicle driving)
- **Improving driver assistance technologies** (lane keeping, emergency braking, collision avoidance systems)

Approach

The project imitates a **two-pronged approach**, with the aim of eventually merging the following directions.

- **1st Direction:** developing Non-linear Model Predictive Control algorithms that determine the behavior of the vehicle.
- **2nd Direction:** observing the limitations of hardware through the testing of fundamental perception methods on our test robot

Methods and Results

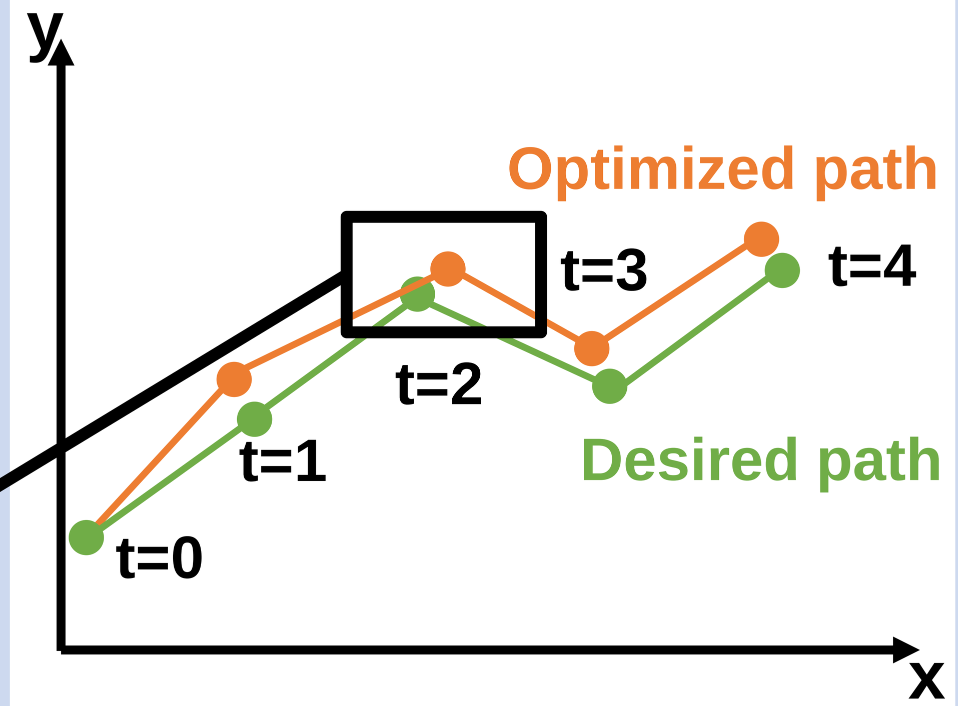
1st Direction - Software

Development of Non-linear Model Predictive Control algorithms (MPC), using Ipopt (optimizing software).

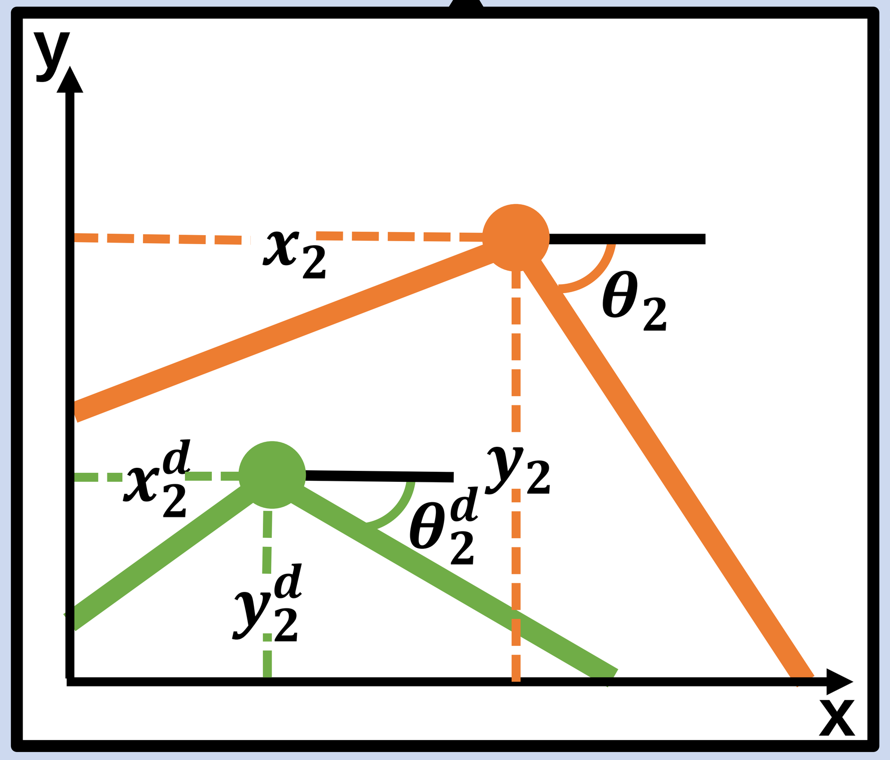
Characteristics and assumptions:

- Perfect localization
- Absence of other vehicles
- Small number of finite time steps
- Bicycle model
- Use of Euler's method

$$x_{t+1} = x_t + v_t * \cos(\theta_t) \quad (1)$$
$$y_{t+1} = y_t + v_t * \sin(\theta_t) \quad (2)$$
$$\theta_{t+1} = \theta_t + \omega_t \quad (3)$$



***Figure(1)**:* MPC finite time horizon and state (orange line: optimized path, green line: desired path)



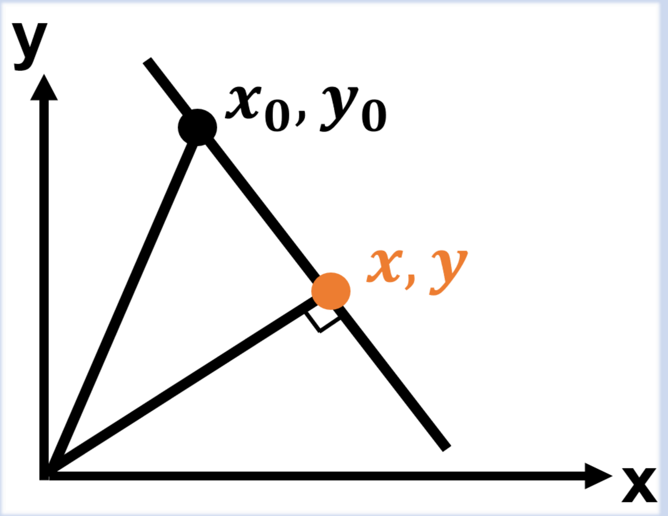
***Figure(2)**:* Magnified view of Figure(1) for t=2 focusing on the MPC optimization parameters

$$\min_{\substack{v_t, \omega_t \\ t \in [0, n-1]}} \sum_{t=1}^{n} \begin{pmatrix} x_t - x_t^d \\ y_t - y_t^d \\ \theta_t - \theta_t^d \end{pmatrix}^2$$

2nd Direction - Hardware

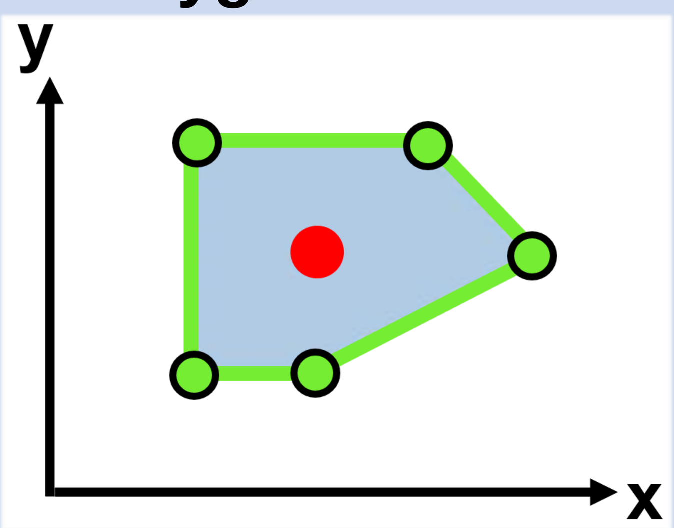
Development of a lane detection algorithm and direct implementation on our current test robot, Anki Cozmo. The following methods are used:

Hough Transform[1]

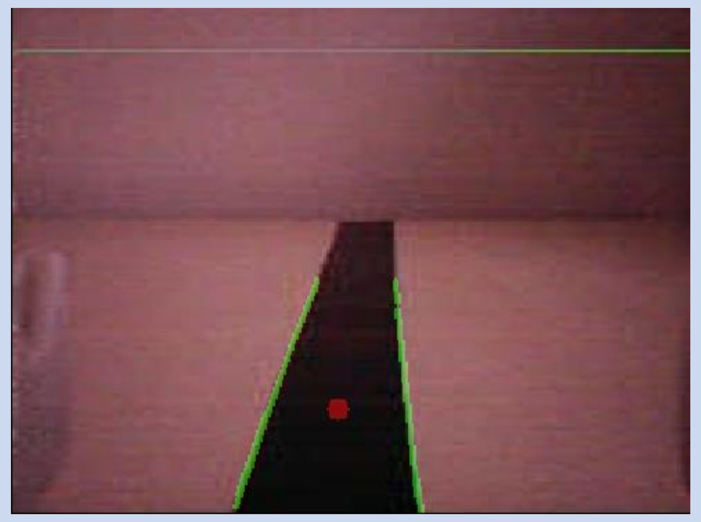


Figure(3): Line segment detection

Polygon Center[2]



Figure(4): Center detection (red point)



Figure(5): Image from Cozmo's view

Take-aways

- Need for high-speed calculations
- Projecting a 2D center of the lane on a 3D environment.

[1]Davies, Machine Vision, 2005, Chapter
[2]Gillies, The Shapely User Manual, 2020

Next Steps / Future Work

- Integration of individual components and testing in simulation (Carla).
- Implementation of the algorithms with the aid of simulated sensors.
- Deployment of an autonomous miniature racecar based only on its onboard sensors at high speed potentially with adversarial obstacles.

Acknowledgements

David and Lorraine Freed Undergraduate Research Symposium, Lehigh University
Dr. Cristian Ioan Vasile and Disha Kamale

LEHIGH UNIVERSITY

P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE