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Optimized Path Following in Platoons Using Non-Linear Model Predictive Control with Geospatial Data

UGRC presentation - Akhil Bandamidapalli, ME20B016

Introduction:

- ➔ An autonomous truck platoon consists of several trucks that follow a **prescribed route** while **avoiding collisions.**
- ➔ This arrangement leads to lesser drag force on the subsequent vehicles, thus **increasing the fuel efficiency.**
- ➔ The challenge is to construct a **central controller** that can decide the required inputs to be applied, so as to enable
  - **Platoon stability**
  - **Collision avoidance**
  - **Path tracking**

An approach to solving this problem is using GPS data in tandem with a model predictive controller…

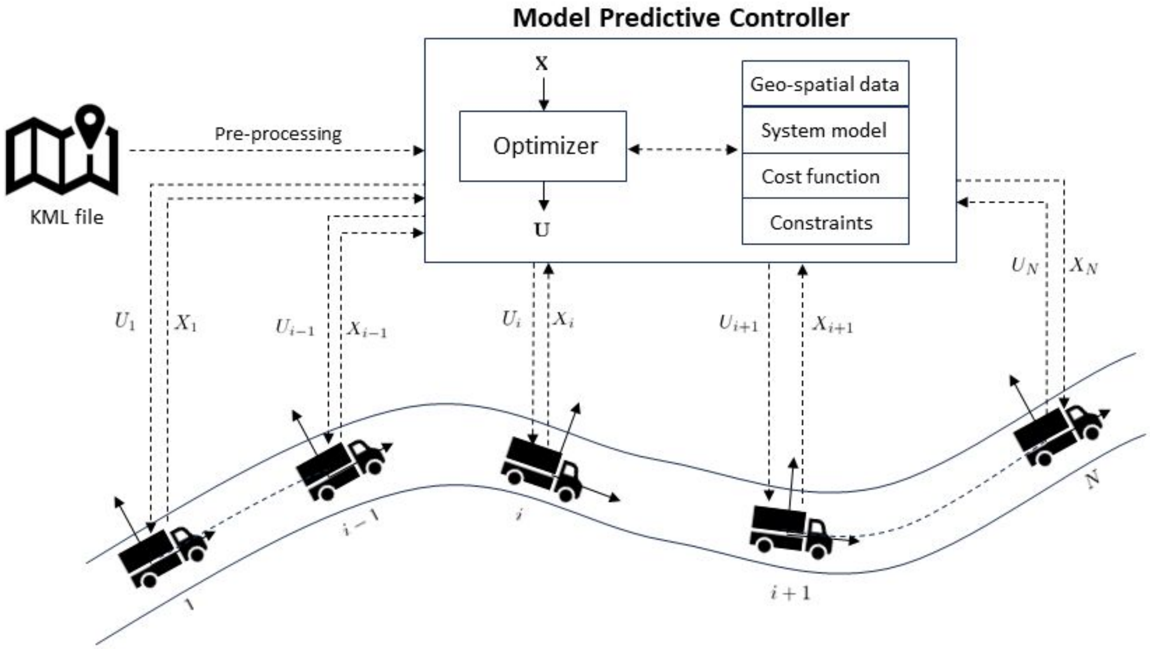
Advantages of MPC over other control methods:

1. One of the main advantages is that, **incorporating constraints** into an MPC problem is very easy.
2. The **horizon control** which MPC enables, allows us to correspondingly **decide our parameter** to ensure best performance.
3. As long as the optimization problem is **convex**, most optimizers can return optimal solutions in minimal time.

Why in platoons?

1. Naturally above advantages!
2. Given the requirement of a central controller, MPC would be an ideal choice

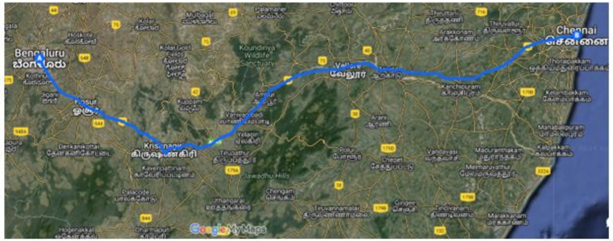
Our approach to the problem:

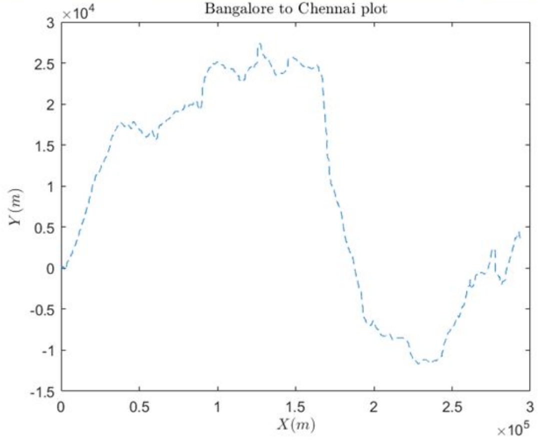


*All pictures were taken from the UGRC report

GPS data -> KML file -> Coordinates:

1. **GPS data** is the standard and most easily accessible data for navigation
2. Google maps offers a feature to export data as a KML file (Keyhole Markup Language)
3. Then, we have written a **python script** to read from the **KML file** and correspondingly give the **x,y coordinates and slope** at every 10 m of the route, to generate a 2D version of the map.





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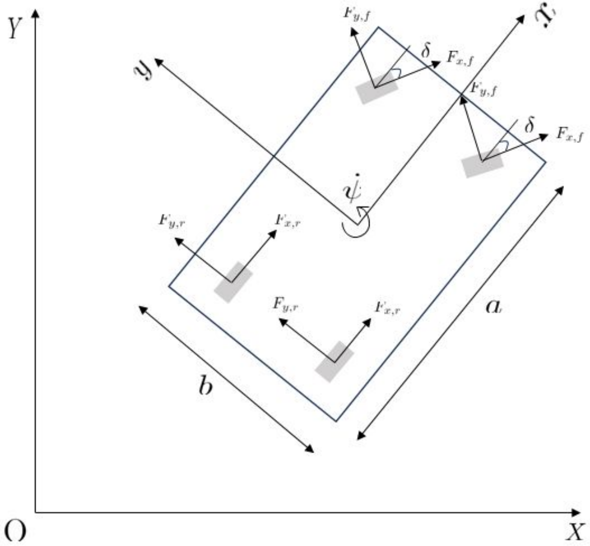
MPC formulation:

System Dynamics:

$$m_i \ddot{x}_i = m_i \dot{y}_i \dot{\psi}_i + 2F_{i,x,f}\cos(\delta_i) - 2F_{i,y,f}\sin(\delta_i) - \frac{1}{2}C_d \rho A_i \dot{x}_i^{\,2} \tag{1}$$

$$m_i \ddot{y}_i = -m_i \dot{x}_i \dot{\psi}_i + 2F_{i,x,f}\sin(\delta_i) + 2F_{i,y,f}\cos(\delta_i) + 2F_{i,y,r} \tag{2}$$

$$J_i \ddot{\psi}_i = a_i \left(F_{i,y,f}\cos(\delta_i) + F_{i,x,f}\sin(\delta_i)\right) - b_i F_{i,y,r} \tag{3}$$



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MPC formulation:

State space formulation:

1. X consists of coordinates, **velocities, yaw angles, yaw rates** at every time t

2. U consists of the **tractive forces on the four wheels, and the steering angle**

$$\mathbf{X}(t) = \left[X_1(t), Y_1(t), \dot{x}_1(t), \dot{y}_1(t), \psi_1(t), \dot{\psi}_1(t), X_2(t) \ldots \dot{\psi}_N(t)\right]^T$$

$$\mathbf{U}(t) = [F_{1,x,f}(t), F_{1,y,f}(t), F_{1,x,r}(t), F_{1,y,r}(t), \delta_1(t) \ldots \delta_N(t)]^T$$

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MPC formulation:

Objective function:

1. Based on our requirements, we write the objective functions, **(12),(13)** are used for **path tracking** whereas **(14)** is used to maintain the **platoon stability**.

2. **(15), (16) minimize the inputs** to the system.

$$J_d[k] = \omega_t \sum_{i=1}^{N} [(X_i[k] - X_{i,ref}[k])^2 + (Y_i[k] - Y_{i,ref}[k])^2] \tag{12}$$

$$J_a[k] = \omega_a \sum_{i=1}^{N} (\psi_i[k] - \psi_{i,ref}[k])^2 \tag{13}$$

$$J_v[k] = \omega_v \sum_{i=2}^{N} [(\dot{x}_{i-1}[k] - \dot{x}_i[k])^2 + (\dot{y}_{i-1}[k] - \dot{y}_i[k])^2] \tag{14}$$

$$J_{u,f}[k] = \omega_u \sum_{i=1}^{N} [F_{i,x,f}[k]^2 + F_{i,x,r}[k]^2 + F_{i,y,f}[k]^2 + F_{i,y,r}[k]^2] \tag{15}$$

$$J_{u,s}[k] = \omega_s \sum_{i=1}^{N} \delta_i[k]^2 \tag{16}$$

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MPC formulation:

Constraints:

1. Since, the inputs have to be bounded, first three constraints are given.
2. To keep a check on the velocities, we use the next two constraints.
3. The final constraints, ensure collision is avoided.

$$F_{\min} \leq F_{if}[k] \leq 0$$

$$F_{\min} \leq F_{ir}[k] \leq F_{\max}$$

$$\delta_{\min} \leq \delta_i[k] \leq \delta_{\max}$$

$$\dot{x}_{\min} \leq \dot{x}_i[k] \leq \dot{x}_{\max}$$

$$\dot{y}_{\min} \leq \dot{y}_i[k] \leq \dot{y}_{\max}$$

$$X_i[k] - X_{i-1}[k] \geq \epsilon_{min}$$

$$Y_i[k] - Y_{i-1}[k] \geq \delta_{min}$$

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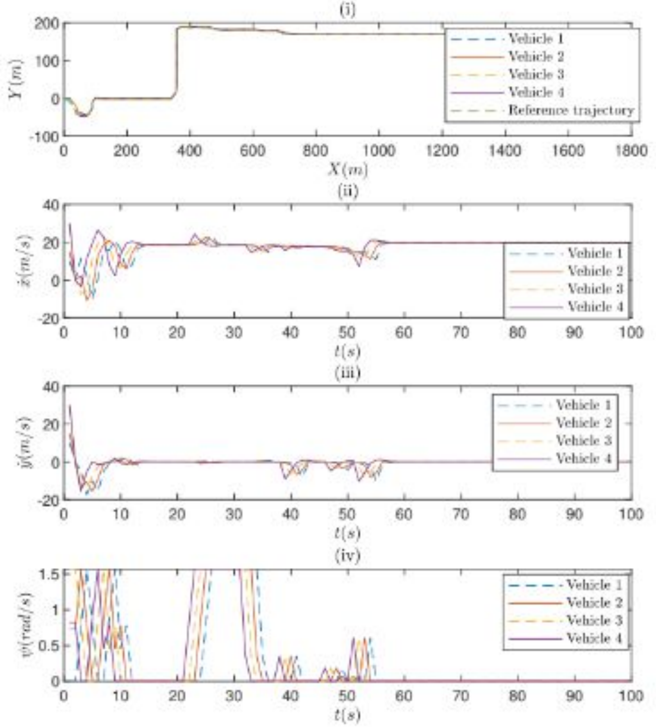
Results:

We ran the designed controller* on the Bangalore-Madras route and obtained the following results:

1. The the path following is almost perfect, with only slight deviations during turns. The presence of steep turns on the route is critical to test it on actual road conditions.
2. However, the controller faces a challenge while turning. Due to the rapid changes in the value of ψi,ref during turns, the controller must optimize them at every iteration, which creates an additional load on the controller.



*The simulations were run on a 1.6 GHz Intel Core i5 Processor, with 8 GB of installed RAM

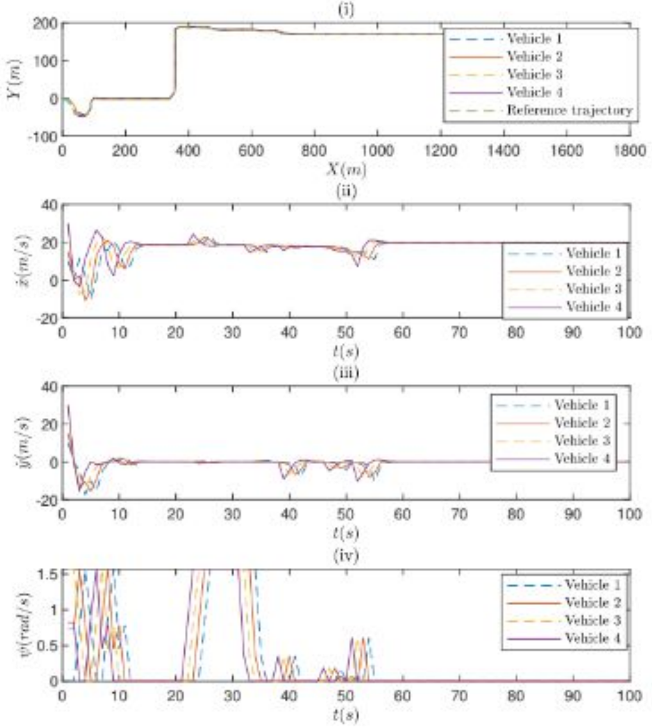
Results:

2. It can be observed that the controller ensures that the local velocity differences between the trucks are minimized during execution.

For example, in segment Y of the route, which is between 0m and 200m, the controller sets yi to 0 and ψi close to π/2. Therefore, the controller tries its best to optimize the route direction.

Hence, we have been able to demonstrate stability and collision avoidance in the platoon.

The complete results can be found in the report shared.



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Conclusions and future work

- Hence, using geospatial data for path-following and collision avoidance while ensuring string stability using a model predictive controller-based approach has been shown here.
- We also illustrate the use of the optimization framework CasADi.
- A three-degree of freedom model further strengthens the capabilities of the above controller to be used in various route scenarios.
- Further research may extend the idea to a real-time environment with dynamically changing routes, this would require the controller to run in real-time which may require new approaches.

Sample references

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