Obstacle Aware Planning on BEVFormer Generated Environments with NMPC-CBF

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Abstract

This work develops an **NMPC-CBF** based planner for autonomous vehicles, leveraging the outputs from BEVFormer [1] – a state-of-the-art framework for generating **Bird's Eye View representations.**

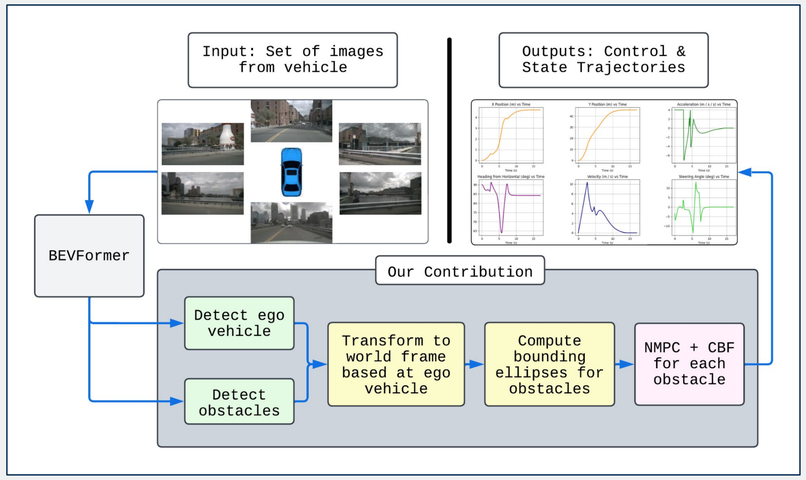
BEVFormer

BEVFormer is a **state-of-the-art** framework to make representations of the real world a vehicle is driving through. It uses spatiotemporal transformers to extract information from multi camera views, producing for each set of images a single image of the scene as viewed from above.

Motivation

- **NMPC** enables the real-time calculation of optimal trajectories by predicting vehicle dynamics over a finite horizon.
- **CBF** enforces safety-critical constraints, such as collision avoidance and maintaining safe distances
- NMPC-CBF can **dynamically adapt to changes** in the environment, with stronger guarantee of safety.
- MPC-CBF with BEVFormer provides a seamless pipeline of perception with robust control. This improves the system's ability to operate in complex, real-world environments.

Methodology



- BEVFormer takes in a set of images and produces a predicted bird's-eye-view of the scene
- Conventional image processing techniques are used to extract the location of ego vehicle (starting position), and locations of other vehicles (obstacles)
- Obstacle locations are transformed to world-frame, bounding ellipse is computed for each obstacle
- NMPC (state-space model below) augmented with a CBF for each obstacle is run to plan a safe and dynamically feasible path from current ego vehicle position to an arbitrary goal location

$$\frac{d}{dt}\begin{bmatrix} x \\ y \\ \psi \\ v \end{bmatrix} = \begin{bmatrix} v\cos(\psi+\beta) \\ v\sin(\psi+\beta) \\ \frac{v}{L_r}\sin\beta \\ a \end{bmatrix}, \text{with } \beta := \arctan\left(\frac{L_r}{L_r+L_f}\arctan\delta\right)$$

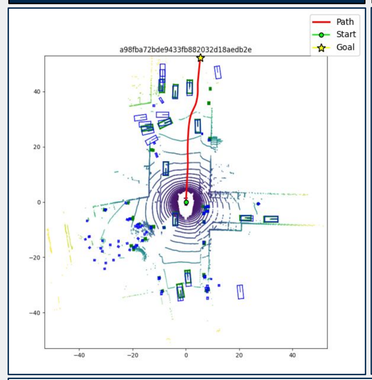
Open-sourced Software

All of our contributions can be found at our open-sourced GitHub repository, linked in this QR code.

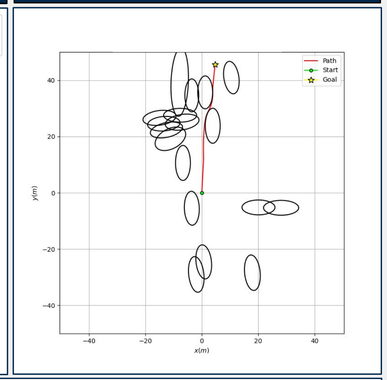
Results

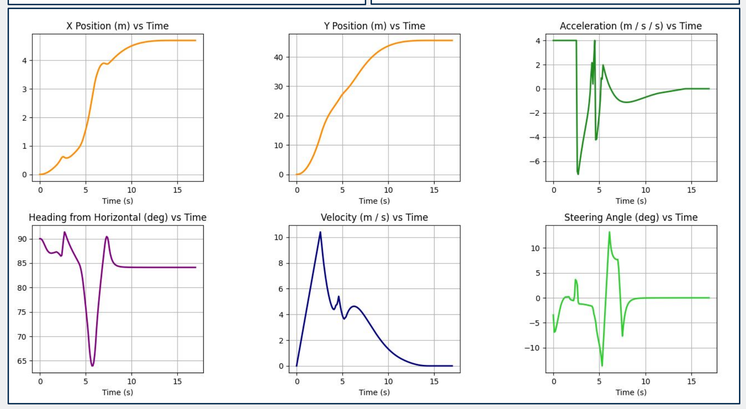
- We successfully implement BEVFormer on the nuScenes v1.0 mini dataset and extended this pipeline by integrating a **Nonlinear Model Predictive Controller** (NMPC) augmented with **Control Barrier Functions** (CBF).
- This enhancement enables obstacle-aware trajectory planning to a given goal location, **ensuring safe and efficient navigation** from the ego vehicle's perspective.

BEVFormer output overlaid with planned trajectory



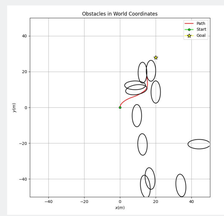
Visual representation of environment used for MPC-CBF





Shortcomings and Future Work

- Planned route can become trapped in concave spaces
- Experiment with longer planning horizon
- Experiment with dynamic tuning of CBF aggression parameter



[1] Z. Li, W. Wang et al. "BEVFormer: Learning Bird's-Eye-View Representation from Multi-Camera Images via Spatiotemporal Transformers," ECCV 2022