CPS: Small: Robust and Efficient Perception System for Autonomous Vehicles (REPAVE)

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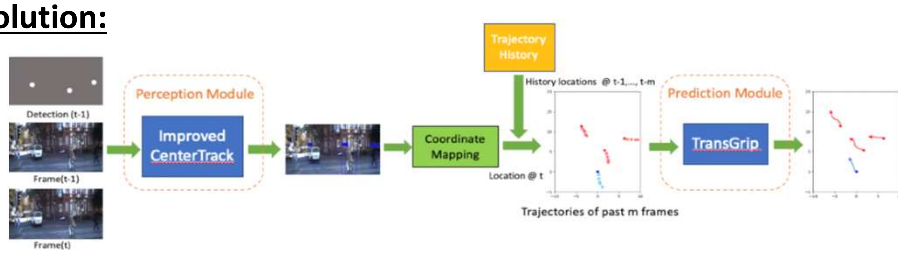
Challenges:

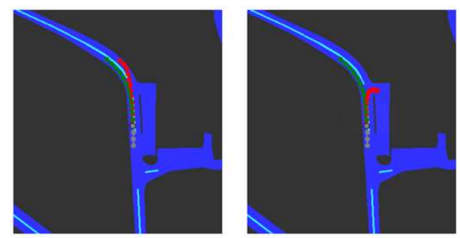
1. Overall performance of E2E framework is highly dependent on performance of both the perception module and the trajectory prediction module.
2. Monocular based 3D detection has low accuracy caused by inaccurate depth estimation and object localization error.
3. Current trajectory prediction models mostly use RNNs which is difficult to model complex temporal dependencies.
4. State-of-Art trajectory prediction models are vulnerable to adversarial attacks.

Scientific Impact:

1. We explore solutions for efficient deep learning models to improve the robustness of the perception systems in complex cyber physical systems such as the autonomous vehicles.
2. We propose an E2E visual-based perception and prediction framework for autonomous driving.
3. We present the first effort of exploring the robustness of trajectory prediction models under map-based attacks.
4. Our E2E model achieves state-of-the-art performance in terms of both detection & tracking, and prediction metrics.

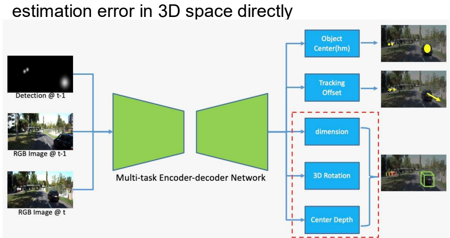
Solution:





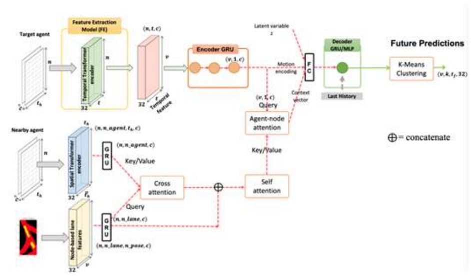
Improving 3D Object Detection based on CenterTrack:

- ***Supervision of 3D Object Projected Centers***: using the projected 3D center c^w as the ground-truth for estimating coarse center c.
- ***Treatments of Training Samples***: discarding all training samples over a certain distance which is set to 65 meters in our implementation.
- ***Pretraining and Finetuning***: pretraining the perception module on a larger 3D object detection dataset to efficiently maximize 3D detection capability before finetuning the tracking head on the typical MOT dataset
- ***Additional Loss for 3D Location Optimization.*** The 3D location of each object in the 3D space is determined by its 3D projected center and depth. We add an additional loss function to compute 3D location estimation error in 3D space directly



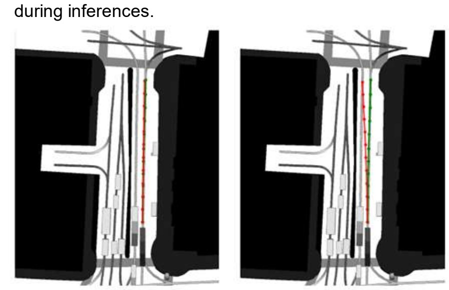
Improving Trajectory Prediction Module:

- ***Improving Trajectory Feature Extraction:*** using Temporal and Spatial Transformers to extract higher quality temporal and spatial features.
- ***Stochastic Trajectory Prediction:*** randomly sampling latent variables z from a standard normal distribution and using K-Means to cluster final trajectory sets
- ***Improving Trajectory Prediction using Map-Based Context Information:*** representing local map as node snippets and encoding nodes through context map encoder



Robustness of Trajectory Prediction (TP) Models Under Map-Based Attacks:

- ***Map-based Adversarial Attacks:*** implementing a brand-new adversarial attack on trajectory prediction models by inserting minor adversarial perturbations to the semantic maps these models use.
- ***Robustness of TP Models using Different Map Representations:*** exploring the robustness of TP models using both image-based and node-based map representation under both white box (PGD) and black box (PSO) map-based attacks.
- ***Effective Defense Mechanisms:*** two effective defense mechanisms against proposed map-based adversarial attacks for both image-based and node-based TP models during inferences.



Broader Impact (Society):

1. This project will advance technologies for autonomous systems, artificial intelligence, robust neural network based design. The developed techniques can be applied various application domains including autonomous vehicles, mobile robots deployed in the home, hospitals and warehouses.
2. The project provides training opportunities for graduate/undergraduate/K12 students and research outcomes are shared with relevant research communities and industry partners such as FORD and Qualcomm.

Broader Impact (Education):

1. Senior Personnel Dr. Montella offered a summer course on Foundations of Robotics to train undergraduates how to program a robot and increase their interests in robotics related careers.
2. Dr. Montella also partnered with another faculty in conducting outreach activities to female middle school students participating in LEHIGH CHOICES program and first year female engineering students in Lehigh PreLusion program to encourage them to consider engineering careers.
3. PI Chuah organizes online professional activities (e.g. mockup interview) for underrepresented CS students.

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