Infrastructure-Based Cooperative Perception at a Traffic Intersection: Overview and Challenges

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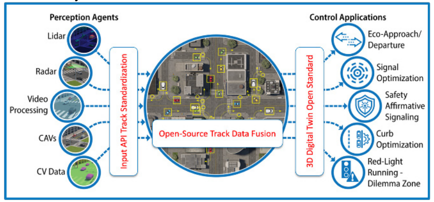
INTRODUCTION & MOTIVATION

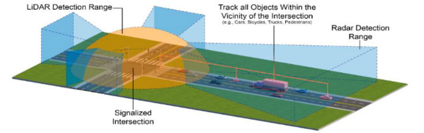
Traffic intersections are crucial and challenging nodes in transportation networks where multiple lanes of vehicles and pedestrians converge.

- About one-quarter of traffic fatalities and about one-half of all traffic injuries in the United States happen at traffic intersections [1].
- To create a safe and robust traffic intersection, it is important to integrate data from sensors of various modalities because each sensor has a different optimal range, resolution, and accuracy.



Data → Information → Control

The **NREL Infrastructure Perception and Control (IPC)** framework integrates perception data from sensors and cooperative shared information from connected autonomous vehicles (CAVs) and connected vehicles (CVs) to perform late-stage track data fusion and create a high-accuracy digital twin of the intersection.



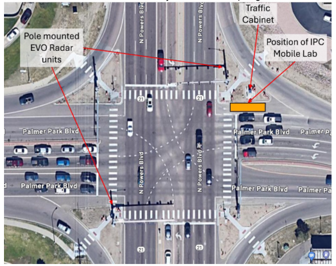
DATA & METHODS

The state-of-the-art IPC mobile laboratory can rapidly deploy multiple sensors and technologies.

- Equipped with latest generation of perception sensors.
- 30-ft extendable mast for sensor deployment.
- Compute for real-time data visualization and control.

Infrastructure Perception and Control Mobile Lab

Test intersection in the city of Colorado Springs, CO



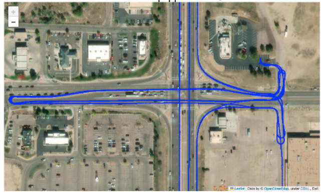
The following sensor suite was deployed at the intersection:

- Econolite EVO Radars (2) mounted on IPC mobile lab.
- Econolite EVO Radars (2) mounted on traffic poles.
- Ouster OS1 Lidar (1) mounted on IPC mobile lab.
- Cepton Vista X90i (1) mounted on IPC mobile lab.
- Axis Q1785-LE Network camera (1) mounted on IPC mobile lab.

Ground Truth

- Emlid Global Navigation Satellite System (GNSS) Reach rover-equipped test vehicle to capture ground truth.
- Emlid Reach RS+ base unit for differential corrections.

Tracks of test vehicles equipped with GNSS receiver



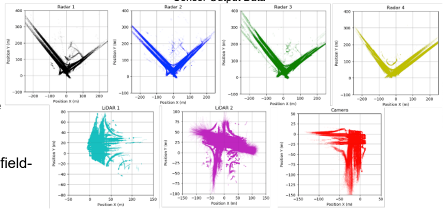
RESULTS AND DISCUSSION

Sensor Calibration

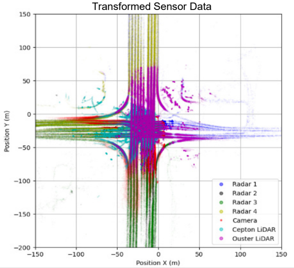
To create a robust digital twin of the traffic intersection, accurate spatial registration is required from the sensors for data fusion.

- Classical calibration methods require calibration object to be detected within the sensor field of view.
- Targetless calibration is challenging for multimodal sensors and needs significant field-of-view overlap.
- The IPC framework uses GNSS trace of vehicles traveling through the intersection to calibrate the sensors [2].

Sensor Output Data



Transformed Sensor Data

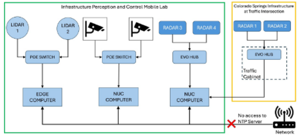


Time Synchronization

Sensor fusion relies heavily on accurate temporal alignment to prevent spatial misalignments.

- Perception sensors typically use Network Time Protocol to synchronize clocks.
- Infrastructure-based systems may lack access to reliable data networks.
- GPS time is highly accurate and can be used for time referencing.

Time synchronization schematic for perception system

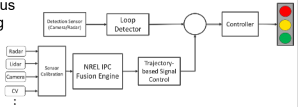


System Health Monitoring

Robust traffic management requires continuous operation, with fail-safe mechanisms ensuring backup systems handle malfunctions.

- The figure shows a schematic of the IPC fusion engine with trajectory-based signal timing control.
- The system employs loop detection/emulation as a fallback when faulty sensor data disrupt the fusion engine output.

IPC perception engine deployment for Signal Control



CONCLUSIONS & FUTURE WORK

This study outlines challenges in deploying the IPC cooperative perception framework. Key highlights include:

- Automatic calibration to align sensor outputs to a common coordinate frame.
- Robust GPS-based clock synchronization for accurate data integration.
- Real-time system health monitoring to ensure accuracy and sensor fidelity.

Future work will focus on:

- Evaluating IPC fusion engine performance with different sensor configurations and testing the algorithm in diverse road environments.
- Exploring vehicle-to-everything (V2X) communication for efficient information sharing.

REFERENCES

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2. Faizan Mir, Stanley Young, Rimple Sandhu, and Qichao Wang. 2024. "Spatiotemporal Automatic Calibration of Infrastructure Lidar, Radar, and Camera with a Global Navigation Satellite System: Preprint." Presented at the 27th IEEE International Conference on Intelligent Transportation Systems, 24–27 Sept. 2024, Edmonton, Canada. www.nrel.gov/docs/fy24osti/89785.pdf.

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