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CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

TRANSFORMING IDEAS INTO SOLUTIONS

Research Notes

Connected Intersection 2.0- Sensor Fusion and Edge Computing for Signalized Intersection

Development of a Concept of Operations document with high-level system design to guide the development of the methodologies and prototype for Connected Intersection 2.0.

Traffic Operations

November 2025

Project Title:

Connected Intersection 2.0- Sensor Fusion and Edge Computing for Signalized Intersection

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WHAT IS THE NEED?

The California Department of Transportation (Caltrans) aims for zero road fatalities and serious injuries by 2050, prioritizing the Safe System Approach. Enhancing safety for vulnerable roadway users (VRUs) at intersections is critical to this goal. However, traditional methods, which rely on pedestrian call buttons and loop sensors, lack the real-time, detailed data needed to address the dynamic and diverse nature of VRU movements.

The current Caltrans Traffic Signal Control Program (CTCSP), which has been in use for two decades, falls behind industry standards. CTSCP fails to meet the increasing demands for compatibility with national standards, which are necessary to accommodate advanced multimodal detection analytics, Transit Signal Priority (TSP), multimodal safety enhancements, and Connected and Automated Vehicle (CAV) applications, thereby hampering interagency coordination. Notably, the archaic nature of CTCSP limits improvements in traffic signal control, hindering the department's ability to operate the system effectively.

To fulfill its vision, Caltrans recognizes the urgency of adopting advanced technologies. Enhanced object detection, tracking, and trajectory prediction for VRUs and all road users at intersections is essential. This shift will provide accurate, real-time insights into the complex environment involving vehicles, pedestrians, cyclists, and scooters. Simultaneously, aligning with current industry standards will enable Caltrans to meet the growing demand for interfacing traffic signals with TSP, enhancing multimodal safety, and accommodating CAV applications.

Caltrans

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By addressing these deficiencies and embracing modern technology, Caltrans aims to not only improve safety for VRUs but also align with industry best practices. The proposed changes will not only contribute to the Safe System Approach but also position Caltrans to lead in traffic signal control, fostering a more responsive and efficient transportation system.

WHAT ARE WE DOING?

This research project proposes Connected Intersection 2.0, which enhances intersection traffic management and safety by integrating advanced sensor technologies and data fusion. Based on the sensors, including LiDAR (Light Detection and Ranging), cameras, and radar, the project will develop Vehicle-to-Everything (V2X) middleware to fuse sensor data for real-time evaluation of traffic conditions and safety hazards. Specifically, the project will perform road user detection and tracking, road user trajectory prediction, and traffic analytics generation, which includes safety-critical-related indicators and safety-enhancing-related metrics. By simulating potential sensor configurations and refining them based on real-world performance, the project ensures optimal sensor selection tailored to the specific needs of intersection traffic control. Additionally, the project leverages Cellular V2X communications to transmit essential traffic data and safety alerts to connected vehicles and VRUs, and dynamically control traffic lights. In the meantime, real-world demonstrations regarding emergency vehicle preemptions and extending walk signals for VRUs will be conducted at the UCLA (University of California, Los Angeles) Smart Intersection or two selected Caltrans smart intersections. This approach aims to improve the responsiveness of traffic systems, ensuring safer and more efficient traffic management. The outcomes will influence future traffic management practices, promoting safer roads through technological advancements.

WHAT IS OUR GOAL?

This project aims to significantly enhance intersection safety and efficiency by developing and deploying advanced sensing and communication systems for next-generation traffic control. The initiative will define specifications for installing cutting-edge sensors, such as LiDAR, cameras, and radar, at key intersections, leveraging their combined strengths to monitor and analyze dynamic traffic conditions comprehensively.

The core of the project involves creating V2X Middleware that fuses data from these multi-modal sensors to 1) detect and track the VRUs and predict their trajectories, and 2) identify and evaluate real-time safety hazards and traffic flow. This fused data will support CAV applications, transmitting critical safety and mobility information via C-V2X technology. Additionally, the V2X Middleware will interface directly with NTCIP-compliant traffic signal controllers, providing inputs that allow for advanced signal control based on detailed real-time inputs, thus enhancing traffic efficiency and safety. By integrating these advanced technologies and protocols, the project aligns with Caltrans' vision for zero road fatalities by 2050, setting a new standard in traffic management technology and improving the safety and efficiency of urban transportation networks.

WHAT IS THE BENEFIT?

By integrating these advanced technologies and protocols, the project aligns with Caltrans' vision for zero road fatalities by 2050, setting a new standard in traffic management technology and improving the safety and efficiency of urban transportation networks. Specifically, the Connected Intersection 2.0 project, which integrates sensor fusion, edge computing, and communication technologies, offers a multitude of benefits to California and beyond, primarily by enhancing road safety, improving traffic control, optimizing traffic flow, and paving the way for future technological

integration in traffic systems. The deployment of these technologies will support the integration of the following use cases at each intersection.

Safety-Critical Use Cases: pedestrian in a signalized crosswalk, emergency vehicle preemption, red light violation warning, near-miss collisions, and wrong-way vehicle detection.

Safety-Enhancing Use Cases: traffic signal priority (freight/transit), intelligent traffic signal system (I-SIG), eco-approach & departure, vehicle counts/turning movements, VRU counts, vehicle classifications, phase interval, pedestrian crossing time, emission estimations, arrival patterns, and queue warning.

WHAT IS THE PROGRESS TO DATE?

The research contract is currently being reviewed by the Department of Procurement and Contracts (DPAC) and has not been executed.

IMAGES

The project team has obtained experience in smart intersection design. Details can be seen in the webpage. As an example, the figure below shows the sensing stack at the UCLA Smart Intersection.

Image 1: The sensing stack at the UCLA Smart Intersection