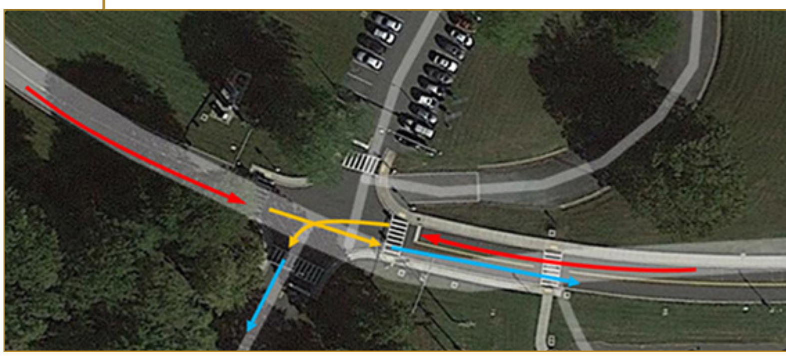
EXPLORATORY ADVANCED RESEARCH

COOPERATIVE PERCEPTION AND CONTROL FOR TRAFFIC SYSTEM OPERATIONS

September 2023

Cooperative driving automation (CDA) technology promises to revolutionize traffic systems in the future. The Federal Highway Administration (FHWA) is paving the way to make this cutting-edge technology a reality with the CDA Research Program (previously known as the CARMA℠ Program) and associated studies.[1,2] See figure 1 for an example of testing being conducted through this program. Despite the promise of CDA innovation, unanswered questions still exist.



Source: FHWA.

Figure 1. Transportation systems management and operations testing scenarios. The arrows show the intended path of travel for each vehicle optimizing its approach to the intersection.[2]

This cooperative system would smoothly integrate and process data inputs from multiple vehicles in realtime, optimizing the signal phase and the vehicle's approach to the intersection.

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For example, CDA environments with mixed traffic (i.e., human-driven and automated vehicles) remain a challenge. Mixed traffic is difficult to predict, and roadside infrastructure sensors for processing the information in automated vehicles may be limited. In the Exploratory Advanced Research (EAR) Program-sponsored 2.5-yr study "Cooperative Perception and Control for Freeway Traffic System Operations," researchers at the University of California, Los Angeles (UCLA) and the University of Cincinnati are addressing the uncertainties of car and traffic movement with their innovative cooperative perception and control framework. This framework fuses various data sources provided by roadside and connected-vehicle sensors to aid the overall perception and coordination of autonomous driving.

CDA RESEARCH

A lot of the research on CDA in the past 5–10 yr has identified the many benefits of and strategies for employing automated vehicles. But much of this work assumes perfect sensing and communication and accurate knowledge of surrounding traffic and vehicle states. Yet, CDA environments with mixed traffic are inherently difficult to fully observe and accurately predict, especially the behavior of human-driven cars. Noise and physical limitations (i.e., range and resolution) can inhibit the ability of sensors embedded in vehicles and roadside infrastructure to gather data.[3] This project's researchers aim to create a cooperative system that integrates communication between vehicles and roadside infrastructure and helps manage these difficulties embedded in a mixed-traffic environment. This cooperative system would smoothly integrate and process data input from multiple sources in realtime to increase the certainty of a mixed-traffic environment.

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OVERVIEW OF EAR PROGRAM STUDY

The study has two phases, laboratory research and field experiments.

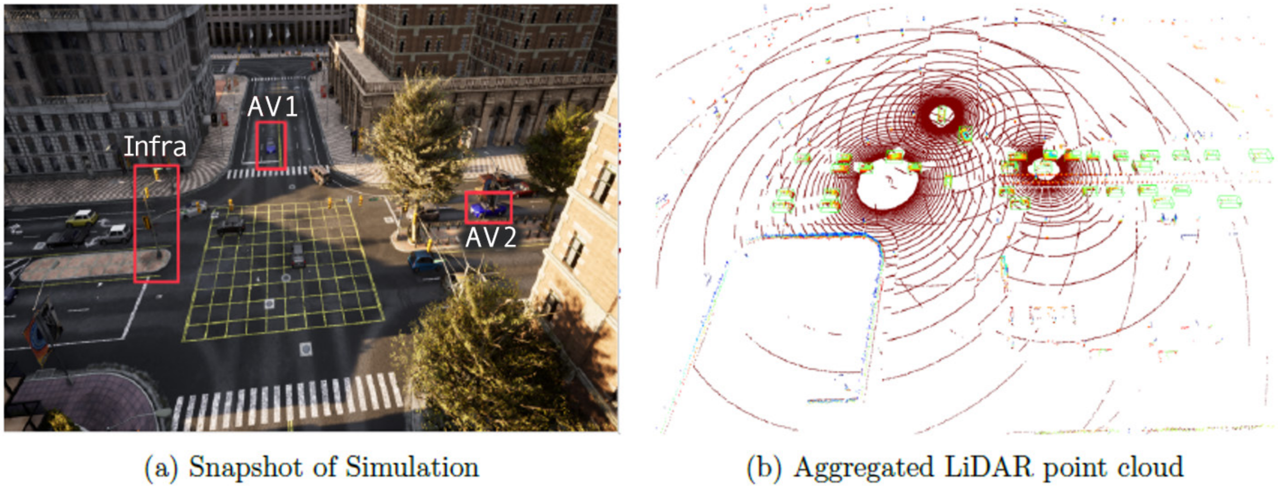
Laboratory Research

For phase 1, which has already been completed, the research team developed a concept of operations, including background research, problems to address, key concepts, operational scenarios, and summary of potential impact.

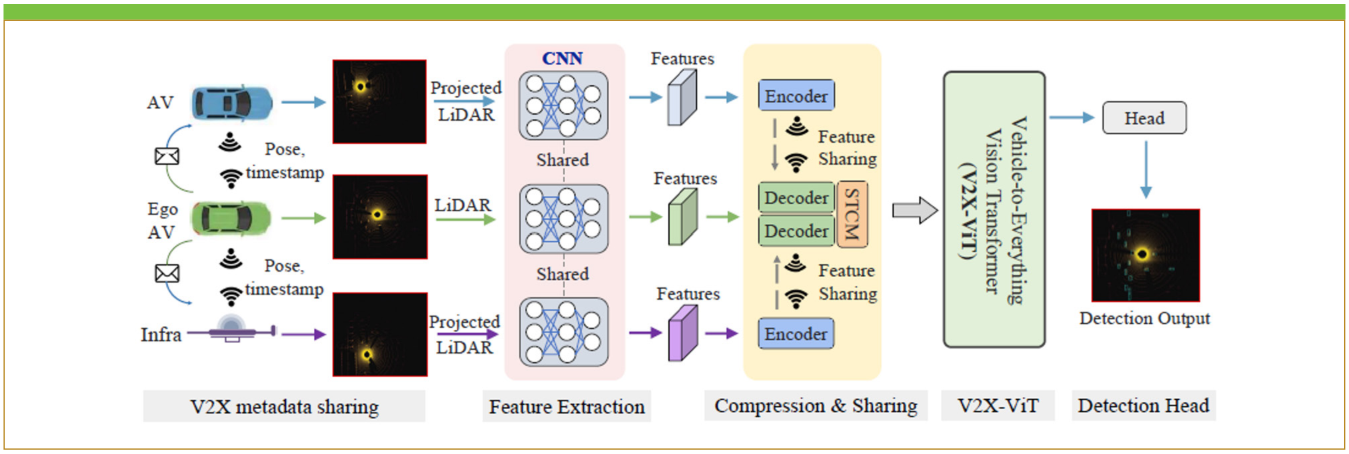
The researchers then focused on developing cooperative perception algorithms. Using a range of data provided by sensors from automated vehicles and roadside infrastructure, the team applied artificial intelligence (AI) and deep-learning techniques to predict the real-time state of a traffic system. Figure 2 depicts the expanded perception range achieved by fusing multiple vehicle and infrastructure sensors of diverse characteristics (e.g., sensor types, sensor placement, sensor accuracy and precision).

Figure 3 presents the architecture of the vehicle-to-everything (V2X) cooperative perception system, including metadata sharing, feature extraction, compression and sharing, a V2X vision transformer, and detection heads. This algorithm leverages attention mechanisms, a “spotlight system” that helps the test vehicle focus on the most important parts of an image or point clouds from other vehicles and/or infrastructure. The researchers developed additional algorithms that incorporate physics-informed AI to fuse V2X detection results with car-following behavior models. These algorithms predict comprehensive vehicle states and trajectories for all vehicles, automated/connected or not, in a mixed-traffic environment.

The research team then developed cooperative algorithms for vehicle and traffic control. Using a decisionmaking AI technique known as the fuzzy inference system (FIS), CDA vehicles were trained to interpret various inputs and take appropriate actions. Figure 4 shows an example of an FIS decisionmaking system for each CDA vehicle platooning and merging.



Source: FHWA.
LiDAR = light detection and ranging; AV = autonomous vehicle; Infra = infrastructure.
Figure 2. (a) Illustration of sensor placement and sensor data view in a V2X environment and (b) illustration of the LiDAR point cloud.[(4)]



Source: FHWA.

STCM = spatial-temporal correction module; CNN = convoluted neural networks.

Figure 3. Schematic overview of the developed V2X perception system.[4]

The project team also created macroscopic and microscopic controls to ensure efficient traffic flow under high-density conditions. These controls included a platooning module for automated vehicle coordination, a cooperative merge module to streamline merges into mainline traffic, and a macroscopic speed harmonization module that regulates vehicle speed limits and platooning gaps. The speed harmonization module employs a reinforcement learning approach within a genetic fuzzy system (GFS) to ensure smooth traffic flow. A GFS is a "learning program" that improves itself over time, like how living things evolve through generations, and it makes decisions based on rules that are not strictly yes or no but have some room for gray area, just like humans do. This module was designed to work synergistically with the platooning and cooperative merge modules for optimal results.

The cooperative perception and control algorithms were then tested through simulations. Since the CDA freeway applications require traffic and vehicle performance evaluation, the team used multiple simulators jointly to evaluate these algorithms. The researchers used Simulation of Urban MObility (SUMO™), an open-source traffic simulator, and Car Learning to Act (CARLA®), an open-source tool that supports the development, training, and validation of autonomous driving systems, for their testing.[5,6]

Field Experiments

Phase 2 includes additional field testing to better calibrate simulation models and verify and validate the performance of developed algorithms. The researchers will use two CDA vehicles that are equipped with advanced LiDAR and camera sensors at the UCLA smart corridor equipped with diverse infrastructure-based sensors, edge computers, and V2X communication capabilities.

CONTACT

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LEARN MORE

To learn more about the EAR Program, visit https://highways.dot.gov/research/research-programs/exploratory-advanced-research/exploratory-advanced-research-overview.

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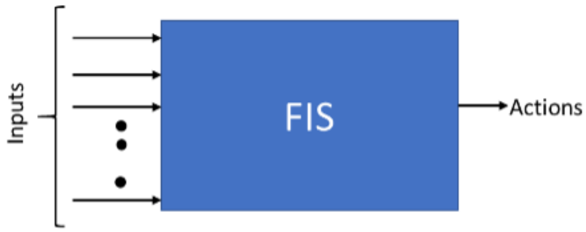

Inputs	Actions
Local information obtained from sensors of the CDA. e.g., Speed of the SDA, speed of vehicles close-by, and length of platoons.	Actions could include: Change lane, Stay in lane, Accelerate, Brake, and Merge to a platoon.
Information shared between CDAs. e.g., Intent to merge, intent to slow down, and intent speed up.	
Centralized information available from the cloud.	

Source: FHWA.
SDA = self-driving agent.
Figure 4. Schematic of the FIS decisionmaking system for each CDA to perform platoon and merge.

REFERENCE

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What Is the EAR Program?

The EAR Program supports longer term, higher risk research with the potential for transformative improvements to the U.S. transportation system. The EAR Program seeks to leverage promising expertise and advances in science and engineering to create breakthrough solutions to highway transportation issues.

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