EXPLORATORY ADVANCED RESEARCH

USING ARTIFICIAL INTELLIGENCE TO IMPROVE SAFETY FOR VULNERABLE ROAD USERS

July 2024

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The risk of fatality and injury for vulnerable road users (VRUs) (i.e., any road user not in a motor vehicle with a protected outside shield, such as pedestrians, cyclists, and wheelchair users) due to traffic crashes remains alarmingly high. A 2023 Governors Highway Safety Association report found that the number of pedestrian deaths in 2022 was the highest since 1981.(1) The Federal Highway Administration (FHWA) has taken a leading role in addressing this VRU safety issue through various initiatives, including the National Roadway Safety Strategy.(2) This comprehensive plan embraces the Safe System Approach, which includes five elements that need to be addressed to achieve zero traffic deaths: safe road users, safe vehicles, safe speeds, safe roads, and post-crash care.(3)

In line with these goals, FHWA's Exploratory Advanced Research (EAR) Program is sponsoring two major studies that harness artificial intelligence (AI) to improve VRU safety. One of the projects, a 3-yr study called PANORAMA: An Interpretable Context-Aware AI Framework for Integrated Real Time Intersection Detection and Signal Optimization led by Southern Methodist University, is developing an AI system that detects VRUs and adjusts traffic signal timing at intersections. The other 2-yr University of Tennessee at Chattanooga-led project, called Advanced Artificial Intelligence Research for Equitable Safety of Vulnerable Road Users, aims to develop a safe, AI-based, flexible, and equitable (SAIFE) system that can identify and track VRUs and prevent potential vehicle-VRU collisions at intersections.

PANORAMA is an integrated computer vision and adaptive traffic control system that adopts advanced machine-learning technology. It is expected to enhance transportation system efficiency, improve safety, promote equity, and reduce construction and operation costs.

PANORAMA PROJECT

Background

The PANORAMA system (figure 1) integrates real-time user intersection detection and traffic signal control optimization into a single AI framework. This system's architecture (figure 2) includes several AI learning modules that enable it to optimize its user detection and traffic signal control decisions based on data input and real-time experience. These modules make the system adaptable to changing operational environments and conditions. The PANORAMA project draws on research developments in adaptive signal control with advanced detection, AI domain adaptation, and interpretable reinforcement learning and control.

Figure 1. Benefits of PANORAMA system.

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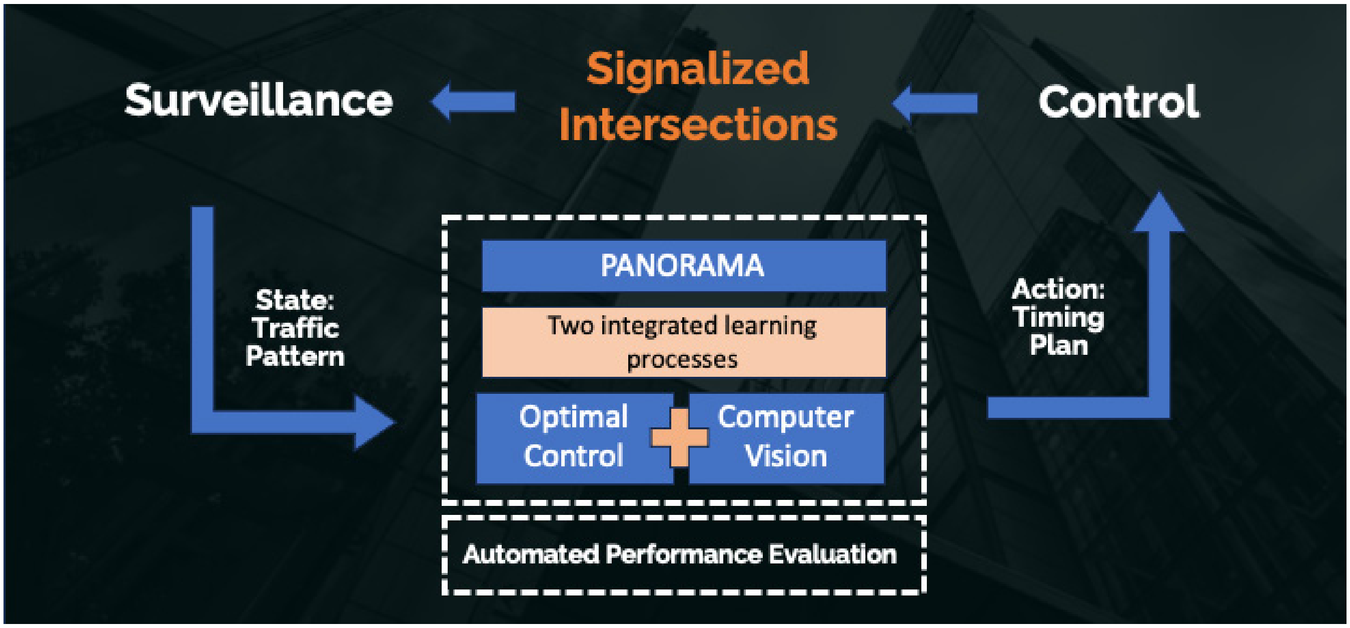

Figure 2. Overview of PANORAMA system architecture.

Adaptive Signal Control with Advanced Detection

Existing radar and video-based detectors at traffic intersections can face occlusion issues (i.e., an object blocking a detector) and vehicle counting errors. Integrating simulations with real-time detection into real-time traffic operations feedback and control has become a way to address this issue. The team seeks to integrate this simulation-supported detection capability with traffic signal control capability into a single algorithm.

PANORAMA comprises two integrated learning processes that consistently analyze the traffic patterns at the intersection using a video feed. It then suggests an optimal timing plan based on the learned patterns.

Domain Adaptation in AI

Though accurate in completing certain tasks, deep neural networks (i.e., a form of AI that recognizes patterns in data) have shortcomings. This AI method assumes the observations in its environment do not change. If the environment, or domain, changes to include different parameters (such as changes in weather, illumination, and object characteristics), the accuracy of a deep neural network suffers, limiting its real-world application. Recent studies have worked on developing deep neural network domain adaptation for environments and datasets with minor changes in color and brightness.

Interpretable Reinforcement Learning and Control

Interpretable AI techniques such as white-box models—which provide a clear explanation for their decisions or predictions—and explainable black-box models—which provide explanations or justifications for their outcomes, even though their underlying mechanism is complex—illustrate the importance of each input variable to the output generated.[(4)] These techniques multiply a set of attention weights by the computed features of the AI model. These weights show how significant each decision variable (input parameter) is for the model when it computes the output of the machine-learning task.

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Such techniques will be used to explain why and how PANORAMA makes certain control decisions in response to detected conditions. This approach aims to enhance end-user trust in the system.

Project Overview

This study consists of four main activities:

1. Developing a virtual reality platform.
2. Developing, training, and validating the AI pipeline for the PANORAMA system.
3. Conducting simulation experimental design and implementation.
4. Conducting technology transfer activities and reporting.

The research team aims to design and implement a three-dimensional virtual reality platform to simulate the main operational scenarios of typical intersections in urban areas. The virtual reality environment represents varying operational conditions in terms of intersection configuration and geometrics, weather and illumination level, traffic demand, and the characteristics of the intersection users.

The researchers then plan to design and implement a novel computer vision object detection model using neural architecture and incorporate it into a new physics-guided deep reinforcement learning methodology in an end-to-end AI pipeline.

Once the virtual reality platform is developed and the AI pipeline is created, the team will design and implement a set of experiments to test PANORAMA in the virtual simulation environment. The experiments will consider a wide range of operational conditions. Performance measures for the detection and control tasks will be reported and compared for these experiments.

Throughout the study, the team will conduct technology transfer activities and reporting to promote the ongoing findings of the research and technological innovations. The research team plans to organize three workshop activities at the beginning, middle, and end of the project.

SAIFE SYSTEM PROJECT

Background

The SAIFE system project aims to detect, classify, and track VRUs at intersections while enhancing resiliency against sensor failure. This system will use various real-time sensors to create sensor fusion algorithms that can accurately classify VRUs. The SAIFE system will then perform AI-based multiple-object tracking and trajectory prediction, which will facilitate situational awareness, such as automated conflict and risk assessments. (See figure 3 and figure 4.)

The SAIFE system project aims to detect, classify, and track VRUs at intersections while enhancing resiliency against sensor failure.

One of the main challenges for multimodal traffic detection is accurately detecting and subclassifying different types of nonmotorized VRUs, especially when they are distant from the sensor and clustered together. The technique for classification primarily depends on feature-based machine learning (i.e., descriptive or discriminative features extracted from objects) and previously trained classification models.

The SAIFE system's use of heterogenous sensors helps to overcome these detection and classification challenges. The calibration of these sensors and the fusion of data received ensures accurate detection and classification at both decision and feature levels. AI-based tracking and prediction algorithms provide an accurate picture of VRU movements that, in turn, can assess their potential risk.

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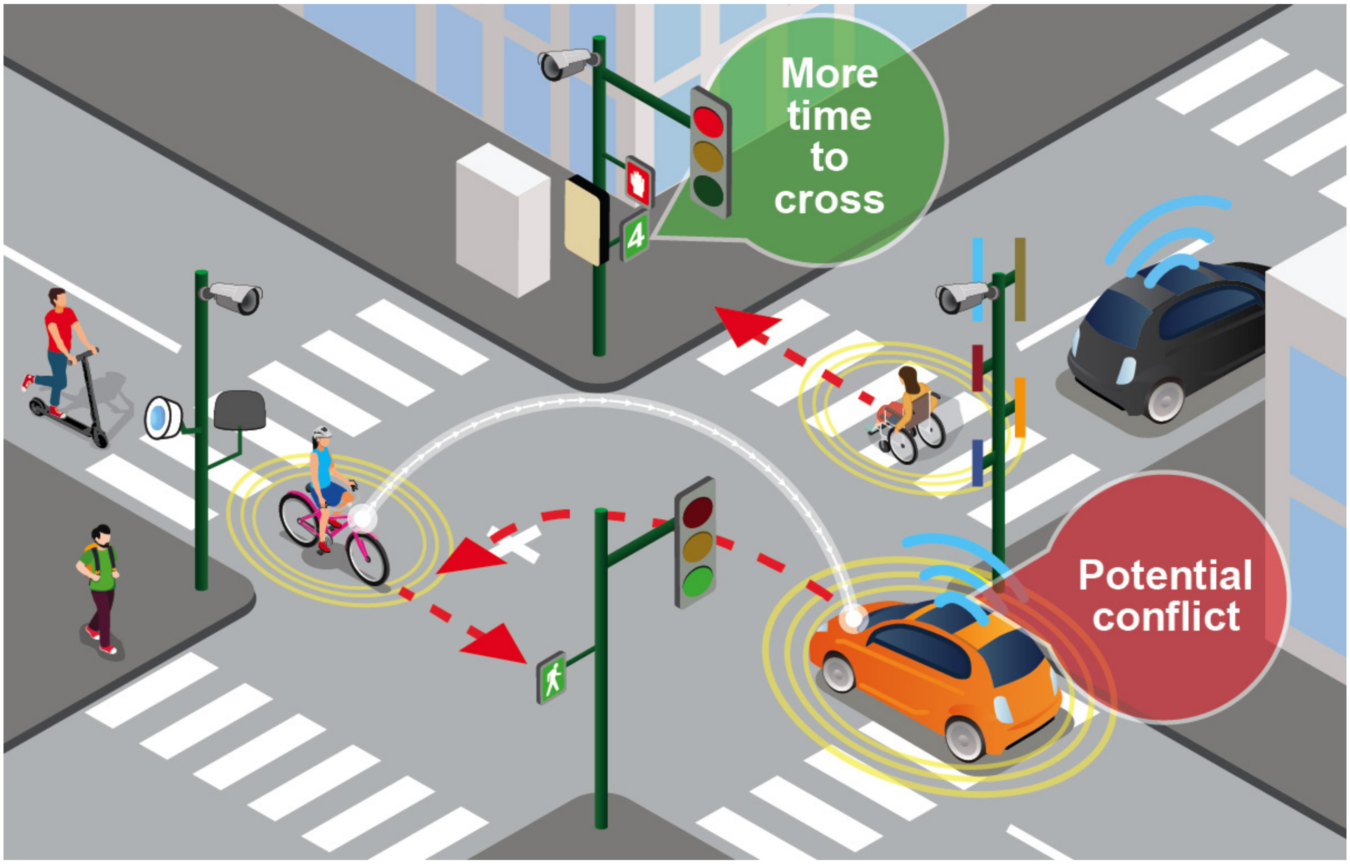

Figure 3. Simulated example of SAIFE system in use.

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Project Overview

The SAIFE system project consists of six tasks:

1. Data acquisition.
2. Sensor fusion for detection and classification.
3. Data tracking and prediction.
4. Automated conflict and risk assessment.
5. Deployment and evaluation in a simulation environment.
6. Field evaluation of the SAIFE system.

The team will draw on traffic intersection data from three different sensors: video cameras, light detection and ranging, and thermal cameras. The objects that appear in a camera view will need to be identified by universal coordinates. To obtain such coordinates, the team will refer to some existing landmarks, such as utility poles, structures, and roadway markings, that calibrate the sensors. This calibration process translates the local coordinate system for each sensor to a universal coordinate system. The sensor fusion process then uses the universal coordinate system to match and enrich features of detected objects. This process will consider influencing factors, such as weather conditions, jittering, and resolution. Using a specialized multisource data integration system, the sensor data will be compiled and then moved into a centralized cloud-based repository for the team to access.

Sensor Fusion for Detection and Classification

The team will investigate different ways to fuse heterogenous sensor data. The typical approach is decision-level fusion, where a high-level information abstraction from each

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sensor is analyzed. However, this approach may lose a significant amount of information during the data abstraction process (i.e., the process of complex details of data being hidden to reveal only the essential features). The researchers will investigate whether a lower level fusion, like a feature level, has the potential to generate better results. An identification and classification system will be developed using this approach to process traffic intersection sensor data.

Data Tracking and Prediction

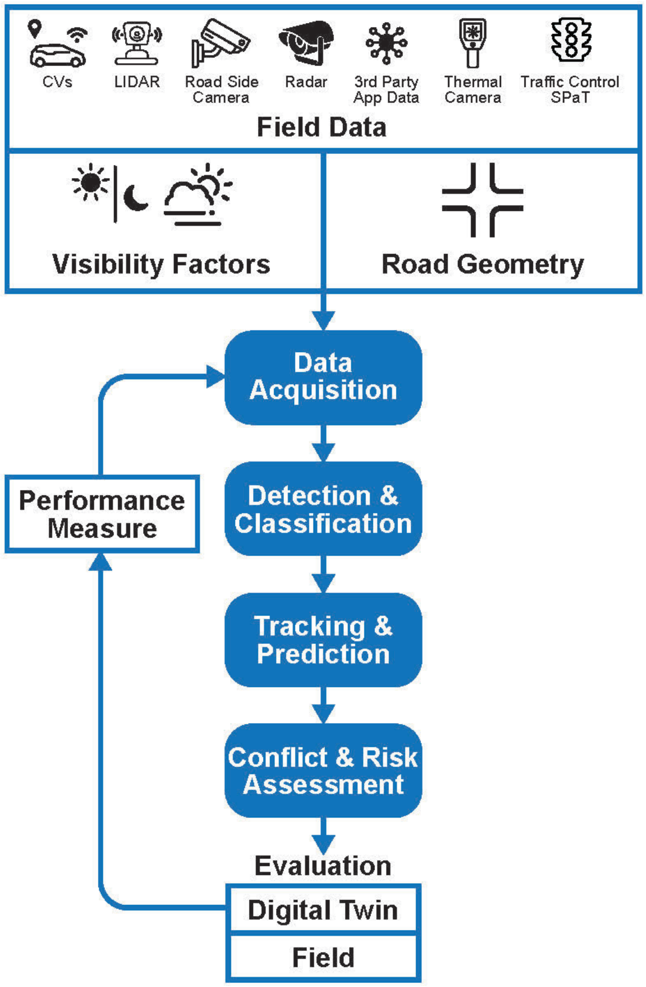
Once the data are compiled and fused, the team will develop a dynamic graph that regularly updates itself as new information emerges and uses a temporal message-passing neural model (i.e., a neural network architecture that captures patterns in temporal data series) to parse out VRU trajectories. VRU interactions at the intersection will be modeled to show where each VRU in the graph dynamically passes and receives messages (pieces of data) temporally to form the final trajectory path.

Automated Conflict and Risk Assessment

The researchers then plan to use the estimated VRU trajectories to identify potential conflicts with vehicles. An algorithm will identify real-time risk trajectories that could lead to vehicle-VRU conflicts. Such potential conflicts will be identified based on historical datasets for trajectory clustering, template trajectory extraction (i.e., identifying the representative trajectory within a dataset), trajectory similarity comparison, and anomaly detection. Other metrics for near-crash analysis, such as time-to-collision, postencroachment time, and distance between stop positions and pedestrians, will be used to evaluate for potential vehicle-VRU conflicts.

Deployment and Evaluation in a Simulation Environment

The team will validate, evaluate, and test the SAIFE system in a digital twin simulation environment. Diverse VRUs and scenarios will be used to test the detection and trajectory prediction functionality of the system.



CV = connected vehicle; LIDAR = light detection and ranging; App = application; SPaT = signal phase and timing.

Figure 4. SAIFE system in proposed framework.

Field Evaluation of the SAIFE System

The researchers plan to deploy components of the SAIFE system at various intersections and a midblock in Chattanooga, TN, to verify the feasibility of the system in terms of performance, latency, and computing needs. The research team will also develop various test scenarios to address the functional requirements of the system and define a corresponding execution plan. These tests will enable the team to accurately document the performance and reliability of the system.

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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.

LEARN MORE

To learn more about the EAR Program, visit https://highways.dot.gov/research/exploratory-advanced-research. The website features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events.

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