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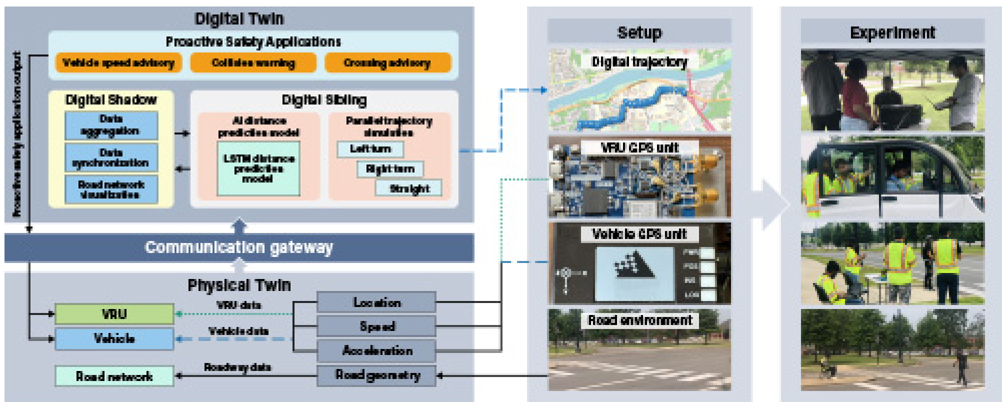
Proactive Safety for Vulnerable Road Users Leveraging Digital Twin Technology

by Muhammad Sami Irfan

Vulnerable road users, such as seniors and children, benefit from a proactive approach that reduces accidents and improves safety.

In a grim outlook for vulnerable road users (VRUs) in the United States, the Governors Highway Safety Association reported that VRU deaths in traffic incidents had reached levels only seen previously in 1981. Any road user who is not in a motor vehicle with a protected outside shield, such as a pedestrian, cyclist, wheelchair user, or construction worker, falls under the definition of a VRU. The estimated figure of 7,485 fatalities within VRUs reverses the decades of apparent improvement in VRU safety. During the same time frame, vehicle drivers have experienced advancements in advanced driver assistance systems (ADAS) aimed at enhancing driving safety for them. However, these systems have not shown significant improvements in VRU safety, as the data indicate. Advancement in VRU safety technology has not matched the pace of ADAS. The Federal Highway Administration has set its target for zero deaths on roads, and the U.S. Department of Transportation's National Roadway Safety Strategy (NRSS) aligns with the same goal. Additionally, section 148 (a)(16) of title 23 of the United States Code underpins the need for States to improve VRU safety on their roads. Consequently, the NRSS emphasizes the Safe System Approach that can anticipate human errors and act accordingly to reduce or prevent crash scenarios.

While measures such as traffic calming can enhance safety for VRUs, they are still reliant on drivers and pedestrians making their own judgment and following traffic rules. In the event of an imminent collision, there is no way to warn either the driver or VRU to take corrective action. In order to support the case of proactive safety principle of the Safe System Approach, the system should be capable of proactively estimating collision risk by predicting trajectories of vehicles and VRUs simultaneously in all possible future safety-critical scenarios. Currently, warning services using connected vehicle technology have been developed that can alert drivers and VRUs of potential collisions, yet there remains a gap in collision predictive capabilities. The objective of this article is to propose a novel approach, leveraging digital-twin (DT) technology to proactively ensure VRU safety along with an experimental case study on VRU-vehicle trajectory prediction for collision warning.



DT-based proactive safety solution for VRU safety and experimental implementation of case study.

Problem Formulation

Pedestrian-vehicle collision scenarios are listed at first, and the problem is formulated as a trajectory prediction problem. A probabilistic approach will help to determine, based on multiple potential simultaneous trajectories for the vehicle and pedestrian, the probability of a certain collision scenario occurring. The following scenarios are proposed for the proactive safety consideration of VRUs: high approach speed of a vehicle, incomplete crossing during phase change, blocked view of pedestrian or vehicle, and road work.

Proposed Solution

A DT-based solution is proposed to proactively tackle the safety of the VRU under the given scenarios. DT systems maintain a real-time digital version of a real-world object or process. The proposed solution approach creates a real-time digital representation of the road environment, incorporating vehicle and VRU trajectory data, roadway geometry, and crosswalk configurations. Through the real-time data synchronization between the real and the digital versions, the DT can be used to conduct parallel simulations of the VRU and roadway.

The input to the system will be the trajectory data for the vehicles and VRUs. Camera or light detection and ranging sensors already deployed along roadways in the physical world can be used to perform accurate position detection of vehicles and VRUs and extract trajectory information. The physical twin will transmit the data to the digital twin via a backhaul system. These data will be used by the digital-twin version to create digital replicas of both a vehicle and VRU. Three distinct subcomponents of the DT will be the digital shadow, digital sibling, and the safety application. The digital shadow aggregates data from physical twin sensors and synchronizes spatio-temporally separated information. The digital sibling component performs parallel simulations of different what-if scenarios of VRU-vehicle collisions. Historical data from previous time frames can be used as input to artificial intelligence-based distance prediction models that can predict the trajectories for enough time in the future to be able to mitigate any risks that should arise. In addition, the digital sibling has to consider each specific problem scenario outlined in a parallel manner to be able to address all possible scenarios. By plotting the predicted distance along the typical paths of a vehicle and VRU, it would be possible to determine whether a potential conflict is imminent between a vehicle and VRU. The simulation results feed into the safety application, which interfaces with the physical twin to send advisory messages and warnings to drivers, VRUs, or roadside message boards. The novelty of this DT-based safety approach is that it can provide reliable measures of safety warning in realtime as a vehicle is approaching a VRU.

Case Study

As a case study of the application, field experiments are being conducted using a real-world VRU and vehicle in a university campus area in Tuscaloosa, AL. A combined Global Positioning Systems (GPS) and inertial navigation systems system is used to collect vehicle location and speed data. The same data for the VRU are collected using a portable GPS unit. Under different scenarios of crossing the road in front of the vehicle, data are collected from the respective sensors. In the case study, the aim was to build the digital twin of the VRU and vehicle and predict a potential collision. The data were fed to a long short-term memory machine-learning model to train it to predict distances of the VRU and vehicle. The predicted distance can be used in parallel simulation scenarios of different possible trajectories to determine the likelihood of a collision. Once the digital model is built and trained, a connection to the physical versions can be made through wireless connectivity between sensors and processing unit. It was found that a proactive crash warning could be successfully generated using the predicted distances of the vehicle and VRU as determined by the DT system.

Muhammad Sami Irfan is a graduate student at the University of Alabama in Tuscaloosa, AL. Muhammad is currently studying civil, construction, and environmental engineering and will graduate in 2025.

For More Information

- "U.S. pedestrian deaths reach a 40-year high" (*https://www.npr.org/2023/06/26/1184034017/us-pedestrian-deaths-high-traffic-car*)
- "23 USC 148: Highway safety improvement program" (*https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title23-section148&num=0&edition=prelim*)
- "National Architecture Reference for Cooperative and Intelligent Transportation" (*https://www.arc-it.net/html/servicepackages/sp57.html#tab-3*)

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