A ROADSIDE UNIT FOR INFRASTRUCTURE ASSISTED INTERSECTION CONTROL OF AUTONOMOUS VEHICLES

IEEE EIT 2025

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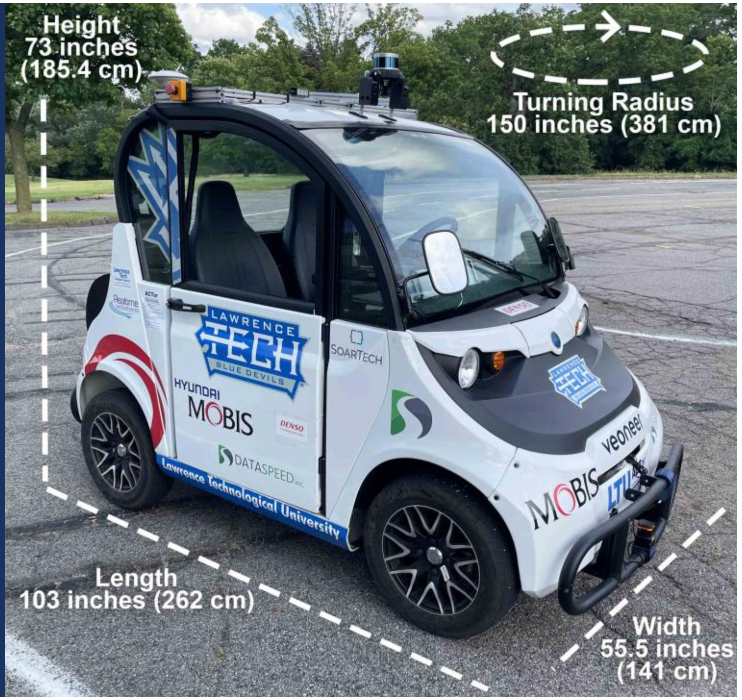

MOTIVATION

- Recent advances made to autonomous vehicle technologies and cellular network capabilities motivate developments in vehicle-to-everything (V2X) communications.
- Crosswalks oriented along city intersections are among the most dangerous situations for pedestrians, accounting for up to 60% of injuries caused by vehicles.
- Traffic idling at lengthy red lights contributes to vehicle emissions and noise pollution.
- Current roadside unit (RSU) deployment costs are exorbitant and are expensive to maintain.

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THIS PAPER

- We propose a cost-effective solution to intelligent and connected intersection control that serves as a proof-of-concept model suitable as the basis for continued research and development.
- To achieve this, we…
  - Simulate our intersection control system in a virtual environment of our Lot H test course using GazelleSim.
  - Establish a connection between the vehicles and RSU to enable vehicle speed control within the intersection.
  - Evaluate a real-world representation of our RSU operating in both an emulated 4-way intersection and cross-walk scenario.
- Validate our fuel-efficiency claims based on a reduction in acceleration and braking through the intersection.

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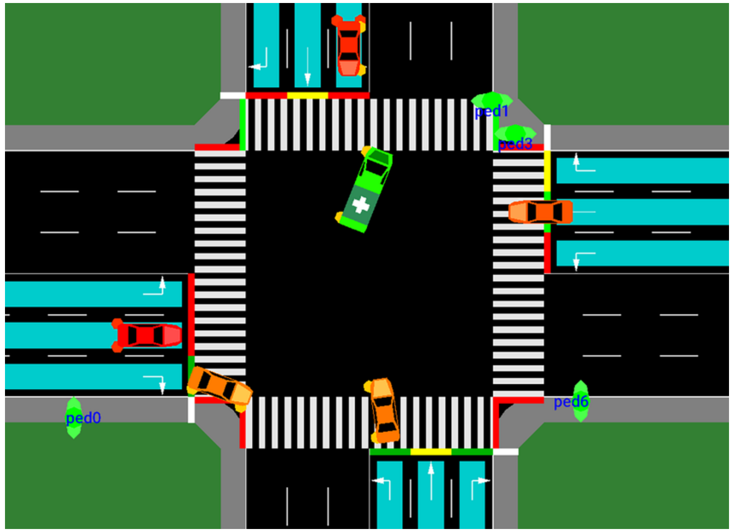
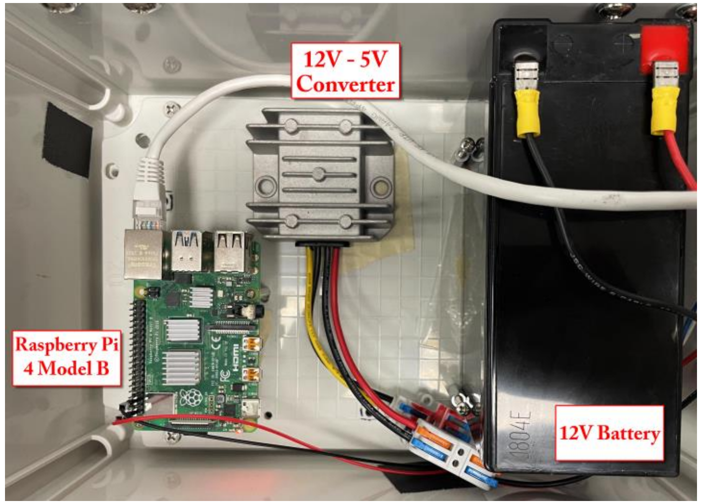
EXISTING WORK

- Most existing research efforts on infrastructure assisted intersection control are tested exclusively in simulation (such as SUMO).
- Obstacles such as variances in the kinematics between vehicle types, uneven pavement, and networking limitations can not be understood by simulation alone.
- Real-world test cases often do not address the cost efficacy of a single unit.
- Infrastructure assisted occupancy grids as a safety feature do not explore velocity control, instead on informing human decision making.



[1]

SYSTEM COMPONENTS

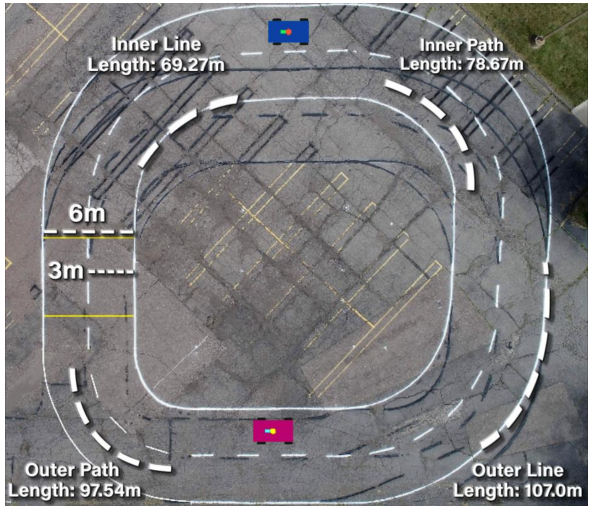


RSU

- Raspberry Pi 4 B
- 12V-5V Converter
- 12V Battery

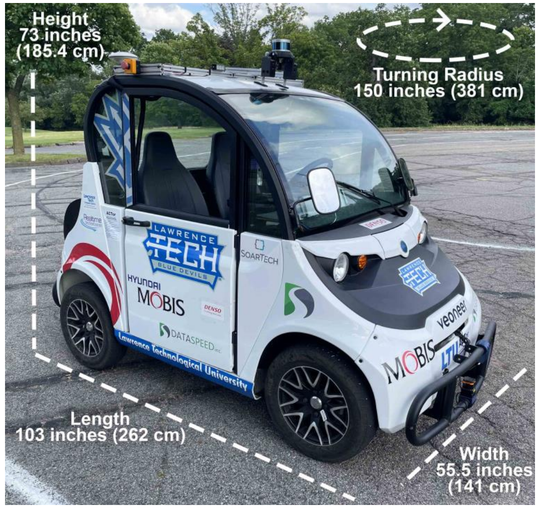
Traffic Light

- 4 individual LED lights
- Relays with controller
- Power supply
- Logic radio module/Wi-Fi
- Arduino Wemos D1 board



Lot H Test Course

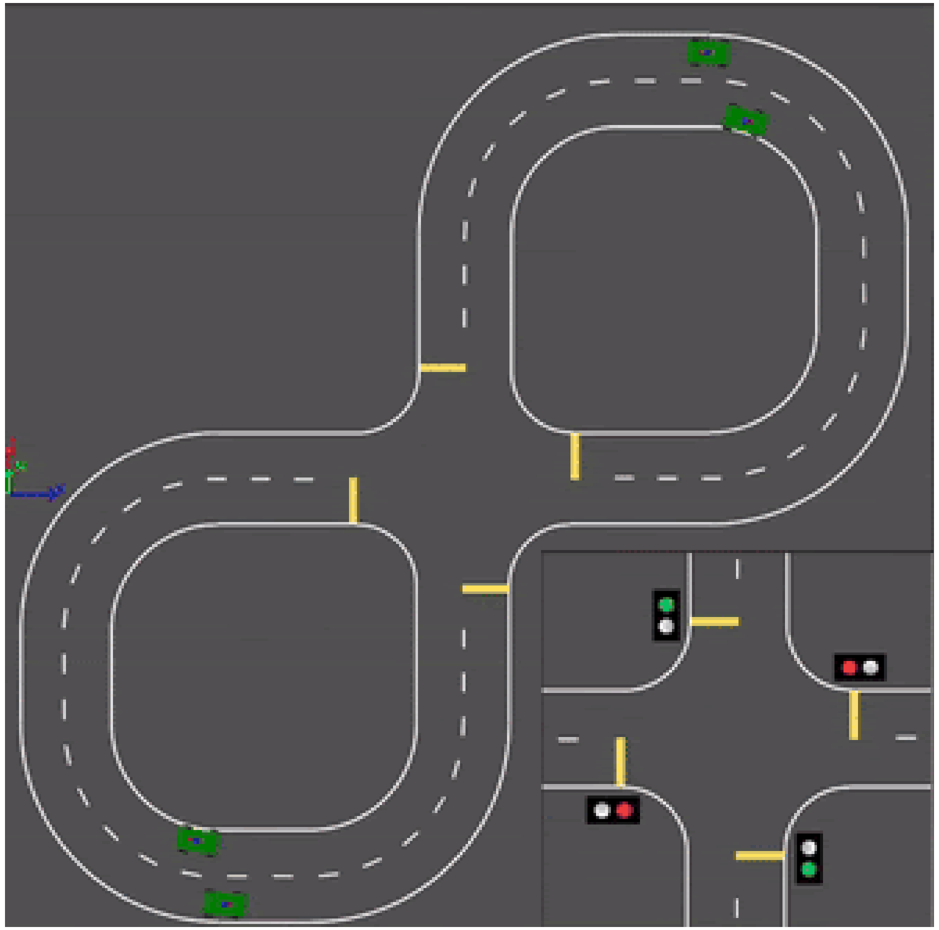
- Southfield, MI



ACTor 1

- Polaris Gem e2 Electric Vehicle
- Dataspeed Drive-by-Wire kit
- HDR Camera
- 2 Swift Piksi GPS modules
- Laptop with ROS

SIMULATION ENVIRONMENT



GazelleSim

- For initial testing of new software features, our algorithms are first implemented in simulation.
- We use a lightweight simulator developed at LTU: GazelleSim.
- Multiple Ackermann steering robots are simulated with turning capabilities identical to the ACTor vehicles.
- This simulator uses a meters per pixel parameter to accurately display the position of both vehicles on the map as they would appear in a real-world test.

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ADAPTIVE SPEED ALGORITHM

```
when the traffic light state changes:

    calculate distance to the closest intersection     # via waypoints
    time to intersection = distance / current speed    # kinematics equation

    if light state is red:
        if time to intersection < time to change state:
            set speed to distance / time to state change
        else:
            maintain current speed

    if light state is green:
        if time to intersection > current state time + time to next state change:
            set speed to distance / time to next state change
        else:
            maintain current speed
```


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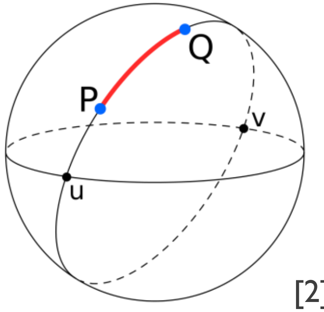
CALCULATING WAYPOINT DISTANCE WITH GEOPY

Definitions:

Let $v = (\phi_v, \lambda_v)$ be the GPS coordinates of vehicle v.
Let $w_i = (\phi_i, \lambda_i)$ be the GPS coordinates of waypoint w_i.
Let $W = \{w_1, w_2, \ldots, w_n\}$ be the set of all waypoints.
Let $I \subset W$ be the set of all intersections.
The distance between points of a sphere $h(\phi_1, \lambda_1, \phi_2, \lambda_2) =$



[2]

$$2r \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)}\right)$$

Find the waypoint w_i with the shortest distance to v:

$$\text{Let } p = \min_{x \in W} h(x, v)$$

Sum $h(w_i, w_{i+1})$ from p to the next intersection:

$$\sum_{i=p}^{k-1} h(w_i, w_{i+1}) \quad : w_k \in I \text{ and } k > p$$

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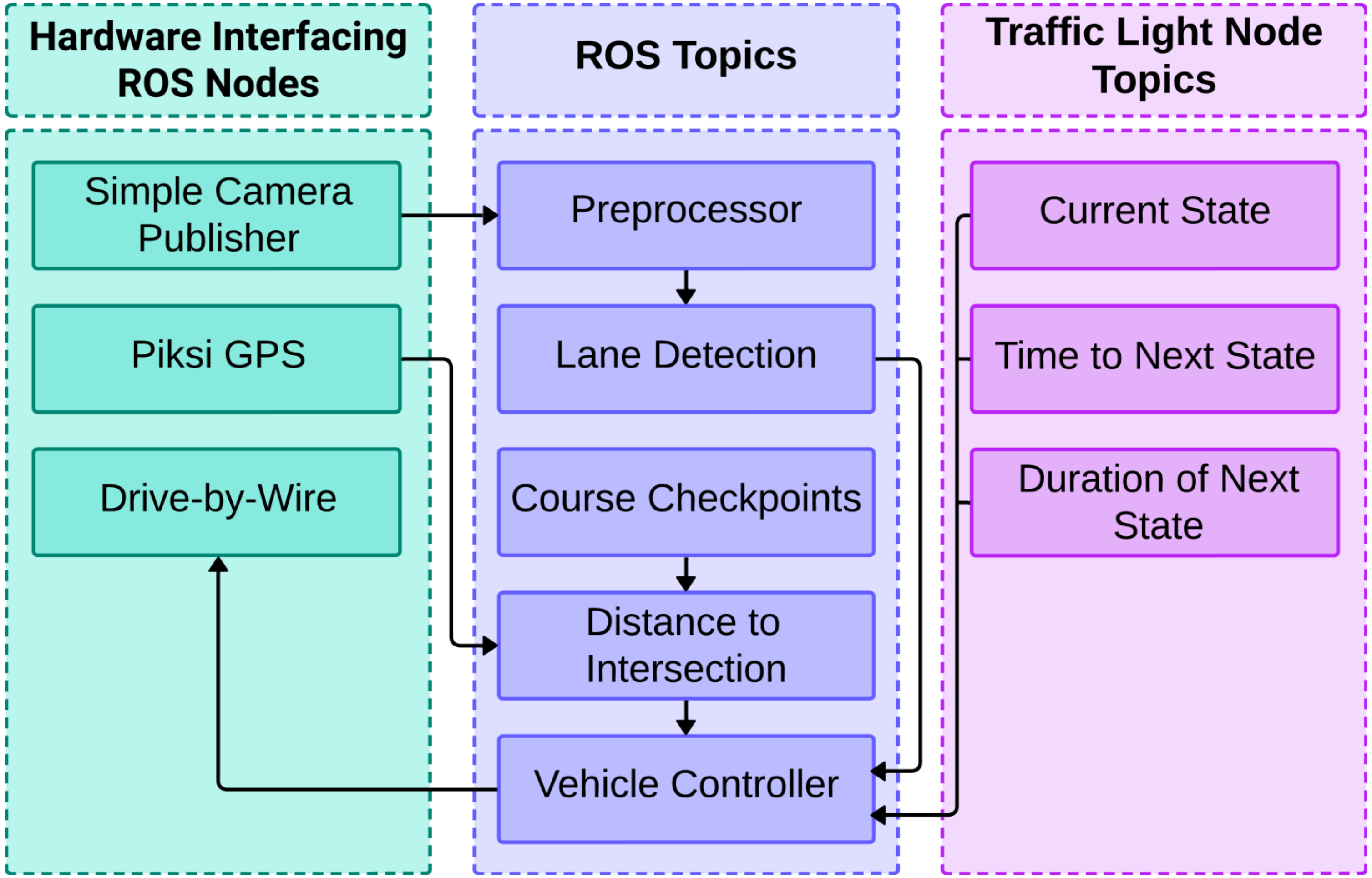
SOFTWARE ARCHITECTURE



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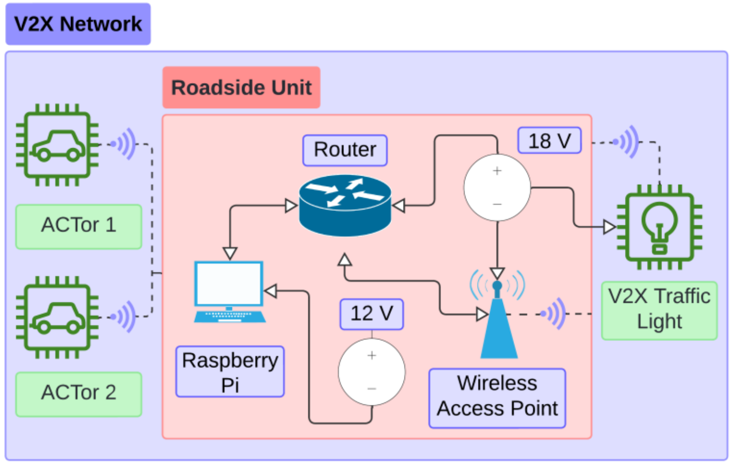

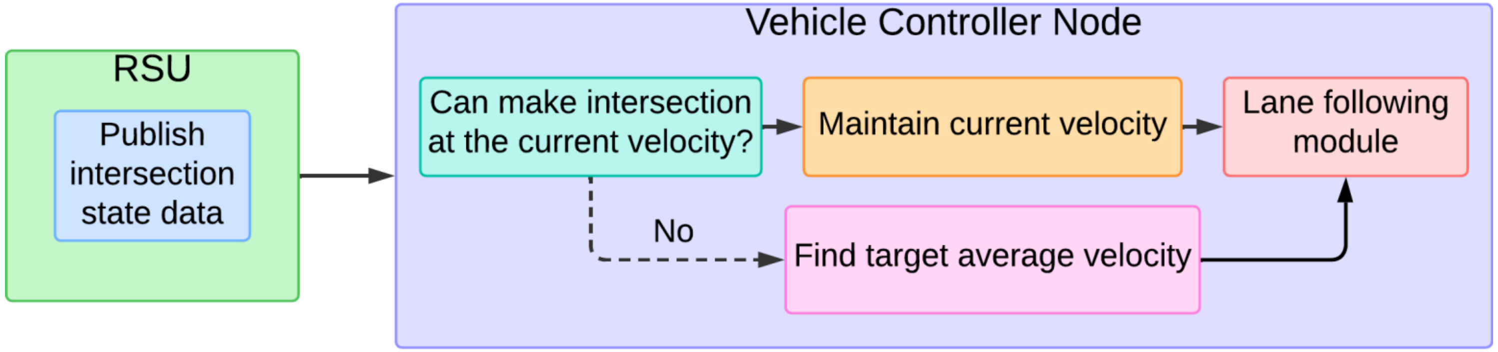

NETWORK ARCHITECTURE

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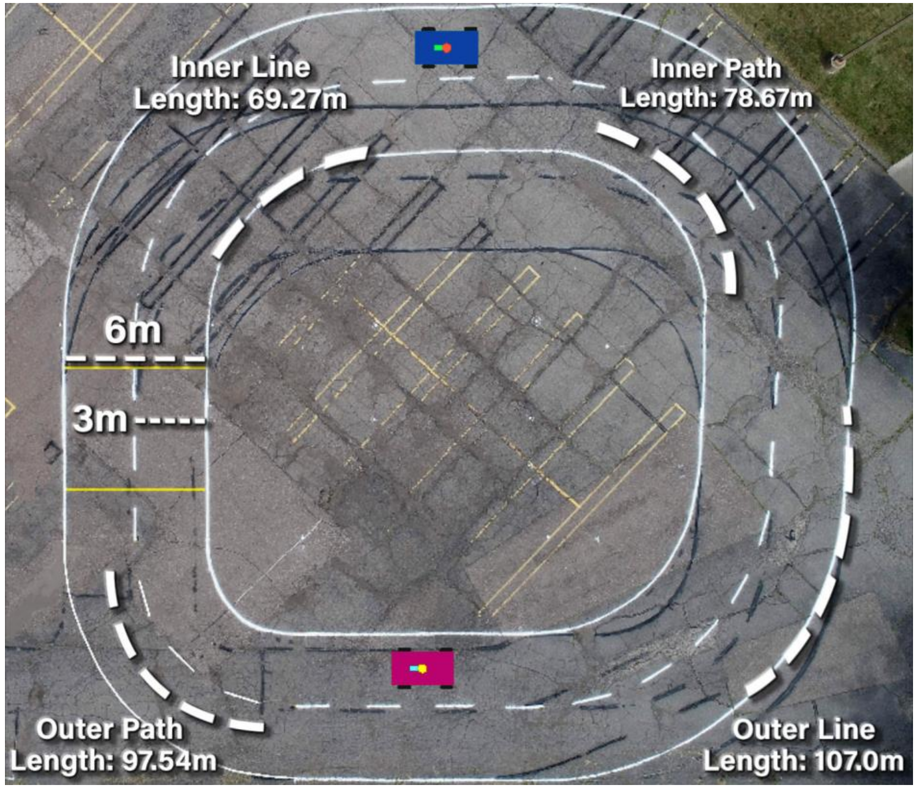
EXPERIMENTAL SETUP

Tested on 2 real-world scenarios: crosswalks and intersections against 3 different light timing configurations.

Data collection for each evaluation begins at the initial green light encountered by the ACTor, which is enabled to drive the first frame that a green light is registered.

For each experiment, we also include a human driver to serve as a control. The driver is instructed to maintain a speed of 5 mph (2.24 m/s) and receives a verbal 5-second warning of state changes to emulate real-world yellow lights.



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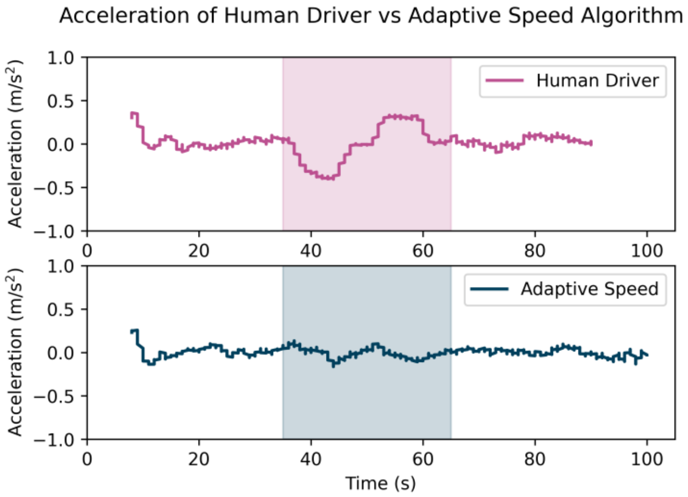
RESULTS – ACCELERATION REDUCTION THROUGH THE INTERSECTION

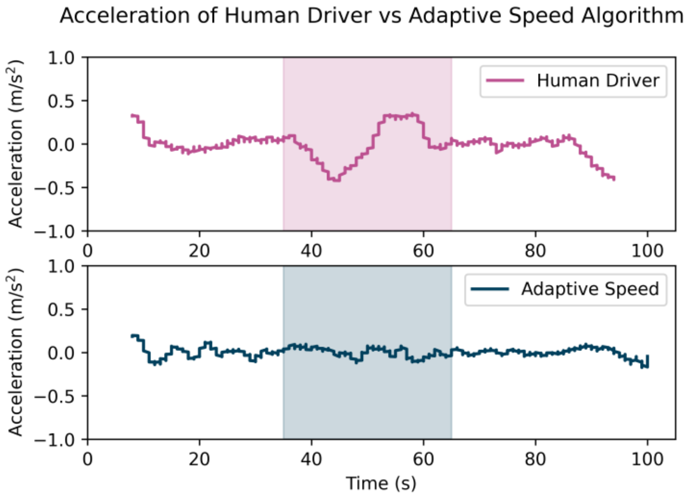
$$\left(\frac{\int_{t=35s}^{t=65s}|a(human)|dt - \int_{t=35s}^{t=65s}|a(adaptive)|dt}{\int_{t=35s}^{t=65s}|a(human)|dt}\right)\cdot 100 \qquad (5)$$

40s green / 10s red light state



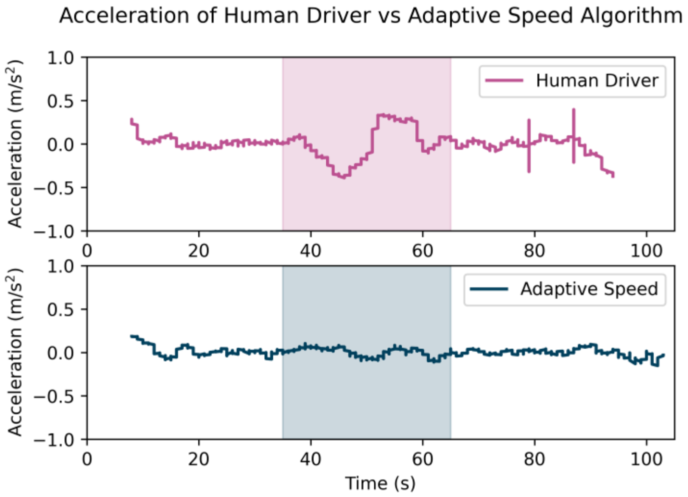
73.15% reduction

25s green / 25s red light state



75.35% reduction

10s green / 40s red light state



73.79% reduction

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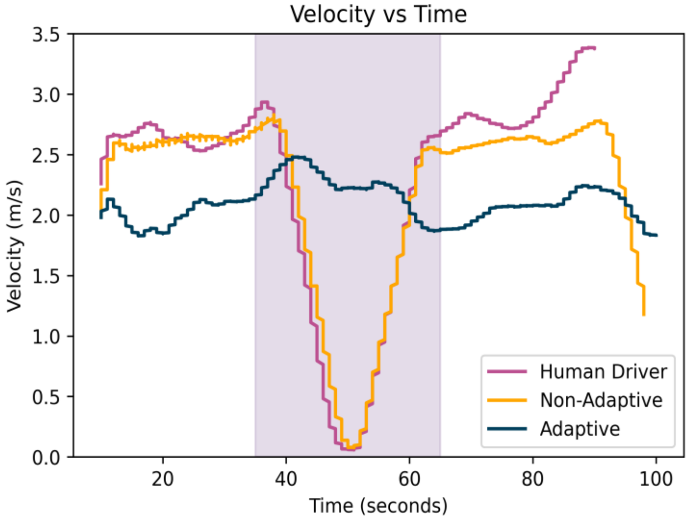
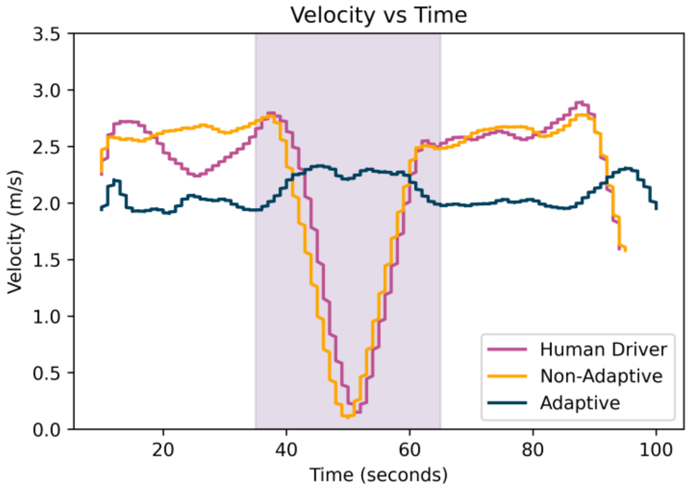
RESULTS – VEHICLE SPEED ANALYSIS

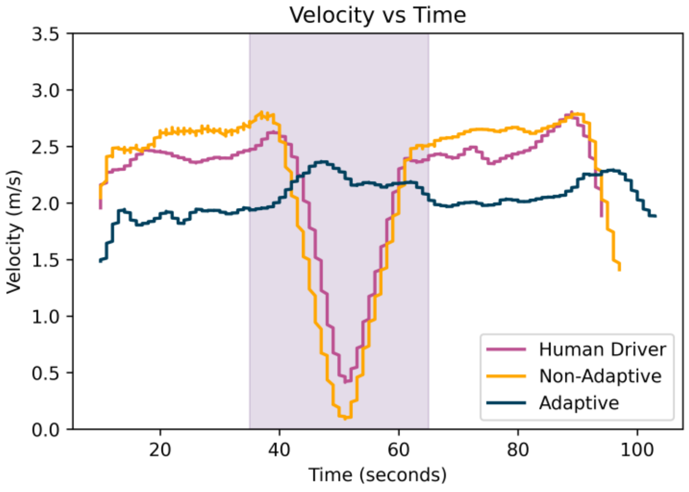
40s green / 10s red light state



25s green / 25s red light state



10s green / 40s red light state



RESULTS – COST EFFECTIVENESS AND SCALABILITY

- As the required RSU density for connected vehicles scales with traffic density, analyzing the cost efficacy of each unit has become a valuable benchmark in this field.
- Cost of ownership must consider factors such as coverage, location-dependent installation costs, energy consumption, and hardware expenses.
- The real estimated deployment costs for an RSU can range from $7,000 to $15,000, with a more comparable cost exclusive to hardware being $6300.
- By utilizing simplified communication protocols and limiting coverage requirements, our proposed RSU can be deployed in a teaching environment for $200.
- We anticipate compute limitations as the number of vehicles managed by the same RSU surpasses 10 and emphasize that our model is intended as a teaching tool, rather than serving as a deployable solution.

SUMMARY AND FUTURE IMPROVEMENTS

- Developed a cost-effective V2X teaching model for adaptive intersection control with a roadside unit for under \$200, significantly reducing costs compared to deployable units.
- Implemented an intersection speed control algorithm on the RSU to reduce acceleration and braking by up to 75%, leading to improved fuel efficiency in gas vehicles and reduced noise pollution caused by red light idling.
- In the future, we will consider…
  - Developing a fail-operational system to better handle connection loss without requiring human intervention.
  - Integrating crosswalk timer data for early pedestrian detection to improve the safety within our pipeline.

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ACKNOWLEDGEMENTS

- This project is supported by the National Science Foundation REU Site Awards #2150096 and #2150292. The electric vehicles used for this research are sponsored by MOBIS, US Army GVSC, NDIA, DENSO, SoarTech, Realtime Technologies, Veoneer, Dataspeed, GLS&T, and LTU.

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- [1] Sun, Guangling & Qi, Rui & Liu, Yulong & Xu, Feng. (2024). A dynamic traffic signal scheduling system based on improved greedy algorithm. PLOS ONE. 19. e0298417. 10.1371/journal.pone.0298417.
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