Autonomous Systems Validation Platform: A Scaled Urban Testbed for Networked Decision-Making

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Motivation

- **Cost & risk:** Full-scale AV testing is costly and hazardous, and proving safety through road testing alone would take hundreds of millions of miles.
- **Data need:** AV developers need repeatable, well-labeled data from realistic signalized urban scenarios.
- **Early validation:** A 1/10-scale urban track lets teams prove out sensors, V2I, and decision logic cheaply, cycling vehicles through testing, logging, and CNN retraining quickly.
- **Gap addressed:** NEMA phasing and a camera–V2I handshake run on real hardware, exposing degraded-link, hazard, and fleet-coordination edge cases that simulation misses.

Testbed Overview

- **Fleet:** Eight Waveshare JetRacer AI Kits with Jetson Nano or Raspberry Pi, camera, and LiDAR.
- **Track:** Modular 40” × 50” urban track with lanes, crosswalks, and NEMA-phased signalized intersections.
- **Network:** Raspberry Pi hosts the signal controller and MQTT broker; vehicles share one Wi-Fi router.
- **Cost:** About $300 per vehicle kit.

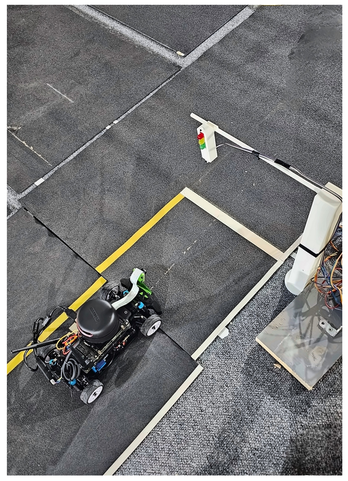


Fig. 1. JetRacer at a signalized intersection.

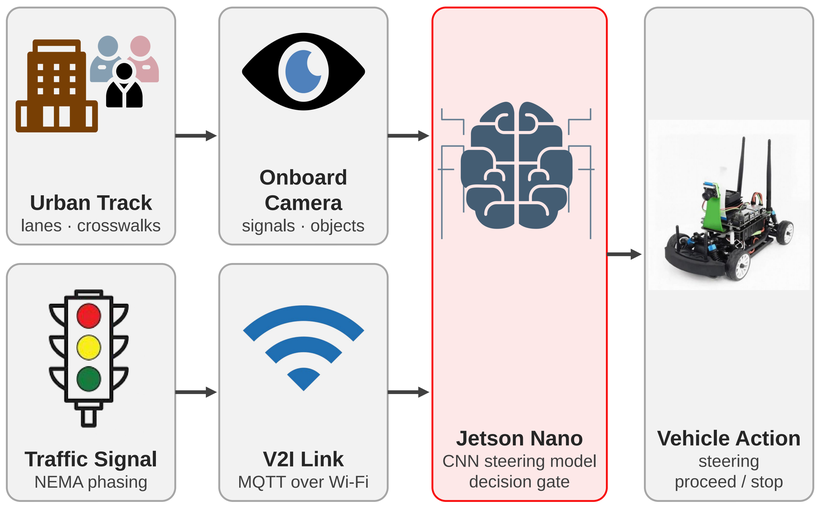


Fig. 2. System block diagram.

System Architecture

- **Sense:** The onboard camera detects lane markings, objects, traffic lights, and pedestrians on the urban track (Fig. 2).
- **Connect:** Each vehicle receives its intersection’s phase state from the Raspberry Pi signal controller over MQTT (V2I).
- **Decide:** The Jetson Nano lane-keeping model and signal detector feed a decision gate that fuses camera and V2I inputs.
- **Act:** The vehicle steers to hold its lane and proceeds or stops at the intersection; steering and throttle run in Docker under ROS 2.

Validation Data

- **Per-frame logs:** Camera frames with lane-keeping and signal-detection outputs.
- **V2I records:** ID-tagged phase states, time to next change, and link availability.
- **Decisions & control:** Time-stamped decision-gate outcomes with steering and throttle commands.
- **Use:** Repeatable datasets for benchmarking new sensors, perception models, and V2I equipment.

Implementation & Results

- **Lane keeping:** CNN trained on a 3,013-image dataset; a tuned Stanley controller gives stable driving at reasonable speed.
- **Signalized intersections:** NEMA ring-barrier controllers publish ID-tagged phase states over MQTT with configurable phase budgets.
- **V2I handshake:** Each vehicle subscribes to its intersection ID and receives the phase state and time to next change (Fig. 3).
- **V2I reliability:** >99.9% V2I availability over a 5,669-frame run of the full perception–decision–actuation loop.

8+	3,013	>99.9%	~$300
vehicle fleet	training images for CNN model	V2I availability (5,669 frames)	per vehicle kit

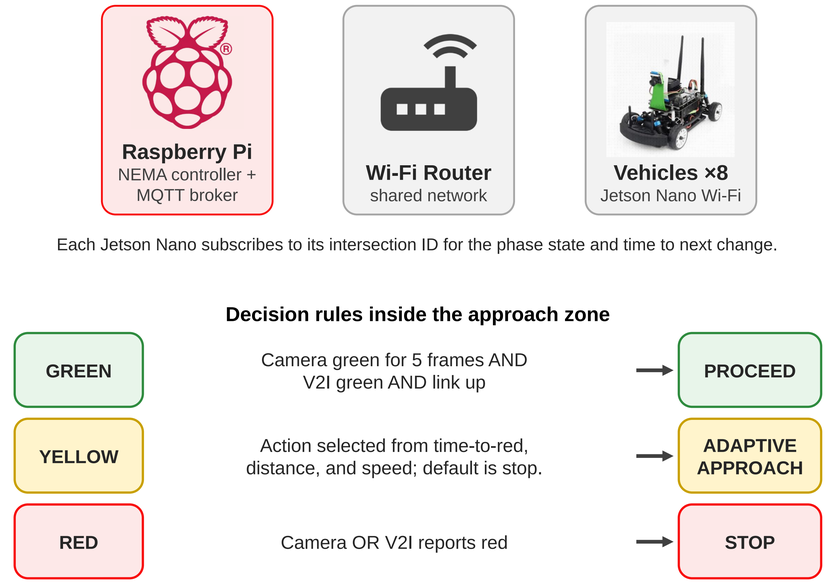


Fig. 3. V2I network and default decision rule.

Future Work

- **Network dependency:** Inject packet loss on the V2I link and measure its effect on vehicle decision time.
- **Yellow-phase decisions:** Use V2I time-to-red and distance to the stop line to decide whether to proceed or stop.
- **Localization:** LiDAR mapping and localization so each vehicle resolves its correct intersection ID.
- **Pedestrian hazard:** A two-wheel robot crosses at crosswalks or jaywalks; vehicles must detect it and stop or avoid a collision.
- **Multi-vehicle coordination:** Eight-vehicle fleet, with vehicle acknowledgments sent back to the intersection.
- **Platoon-level advisory speed:** JetRacers use the V2I link to adjust speed ahead of signal changes, reducing stop delay and travel time across the fleet.

Conclusion

- The testbed closes the loop between signal infrastructure and vehicle autonomy at 1/10 scale, producing repeatable V2I and driving data for autonomous systems validation.
- Lane keeping, signal-aware decisions, and V2I messaging run together on low-cost hardware with >99.9% link availability.
- It offers a low-risk bridge between simulation and full-scale deployment for networked decision-making research.