JUNE 20-24, 2022

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

REAL-SIM

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PROJECT ID: EEMS101

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Argonne NATIONAL LABORATORY · BERKELEY LAB · Idaho National Laboratory · NREL NATIONAL RENEWABLE ENERGY LABORATORY · OAK RIDGE National Laboratory · Pacific Northwest NATIONAL LABORATORY

PROJECT OVERVIEW

Timeline

- Project Start Date: Oct. 2020
- Project End Date: Sept. 2023
- Percent Complete: 40%

Barriers

- Modeling and simulation environments are not all inclusive for all scenarios.
- Lack of standard co-simulation tools or hooks across vehicle and traffic environments.
- Computational requirements of complex environment simulation.

Budget

- Total Funding: $3.58M
- Funding per Year:
  - FY 21: 1.12M
  - FY 22: 1.23M (Planned)
  - FY 23: 1.23M (Planned)

Partners

- Lead
  - Oak Ridge National Laboratory
- Partner
  - Argonne National Laboratory
- Collaborations
  - American Center for Mobility (ACM)
  - IPG Automotive

OBJECTIVES AND RELEVANCE

- **Relevance:**
  1. A system of systems approach is required to properly manage vehicles equipped with advanced driver-assistance systems (ADAS), connected and autonomous vehicle (CAVs) technologies, their interactions with the surrounding environments, traffic networks, traffic control, and the various scenarios that greatly effect each one of these.
  2. Expensive in-field experimentation generally captures 'focused' datasets- not providing sufficient detail to produce a digital twin or explain unique events during future experimental analysis. Current on-road connectivity implementations are built upon large infrastructure investments at permanent locations. (Corridors / test tracks / etc.)

- **Objective:**
  1. Expand the capabilities of the VPPG Core-tools project feedback loop to include capabilities of digital twins as well as greater real-world correlation by utilizing on-road/track data in a closed-loop process for validation of the performance of controls and simulated scenarios/environments.
  2. Incorporating joint vehicle and infrastructure experimental platforms can provide a "full picture" of costly experiments for further analysis OR replication in a digital environment where more variables may be controlled. Smaller scale, portable systems built on 'nodes' offer flexibility and control of research activities, enabling experiments on controlled roadways, or public roads.

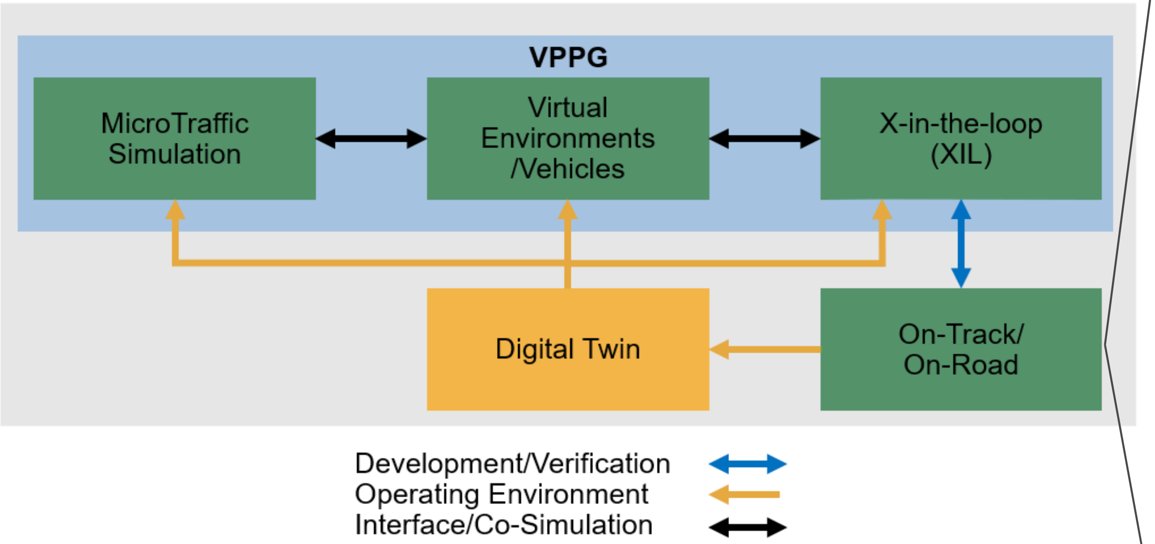
MILESTONES

Date	Milestone	Status
March 2022	Mobile DAQ revisions enabling infrastructure and/or vehicle data collection of video, connectivity, and traffic signal data operating in a laboratory environment. **(Task 1.3 ANL)**	**Complete**
June 2022	Completed multi-layer digital twin of the Shallowford Rd Corridor for simulation and HIL validation exercises including support of 1C project 1591. **(Task 2 ORNL)**	**On Track**
Sept. 2022	Demonstration of vehicle and infrastructure mobile DAQ components in use for experimental testing on controlled roadway or track. **(Task 1.3 ANL)**	**On Track**

APPROACH

OAK RIDGE National Laboratory

Real-Sim



Argonne NATIONAL LABORATORY

Develop a mobile connectivity-enabled platform to coordinate and capture on-road experimentation

Vehicle Component

Capturing 'full picture' vehicle operation **AND** environment during experimentation

Infrastructure Component

Providing control and data capture of traffic flows and infrastructure components

Direct support through data for multiple SMART 2.0 efforts

APPROACH

Task 1

- **Subtask 1.1: Sensors - XIL and virtual environment 2.0.**
- **Subtask 1.2: VPPG microtraffic 2.0, enhancements to include SPaT, V2X, and traffic control XIL applications.**
- **Subtask 1.3: Development of portable platform for V2X testing and data collection to enable XIL validation.**

Task 2

- **Task 2 – Real-Sim platform and digital twins**
- **Digital Twins to be created for support of this project and SMART 2.0**
  - Chicago
    - Randal Rd.
  - Chattanooga
    - Shallowford Rd.
    - MLK Blvd.
  - Tuscaloosa, AL
    - 3 Intersection Area
  - ACM
    - improvement of current digital twin

Task 3

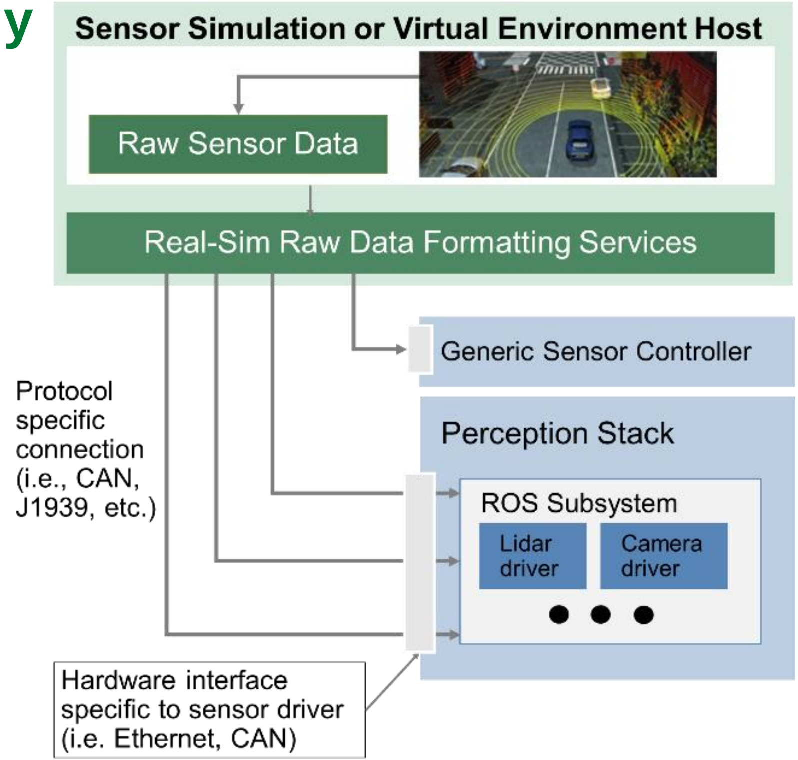
- **Task 3 – Validation of the Real-Sim Platform using Current On-Road/Track EEMS Projects**
- **Projects that will support this effort.**
  - Regional Mobility Project
  - ACM Model Validation Project
  - EEMS096
  - EEMS095
  - EEMS061

ACCOMPLISHMENTS AND TECHNICAL PROGRESS

TECHNICAL ACCOMPLISHMENTS

Task 1.1: Sensor Integration Methodology

- The approach for the integration of simulated AV sensors prioritizes the use of available raw sensor data interfaces of virtual environment simulation tools.
- The raw data is formatted using ORNL-developed services that emulate the communication protocols of the real sensor hardware.
- The formatted data is sent to the same network interface and ROS drivers used by the real sensor hardware.

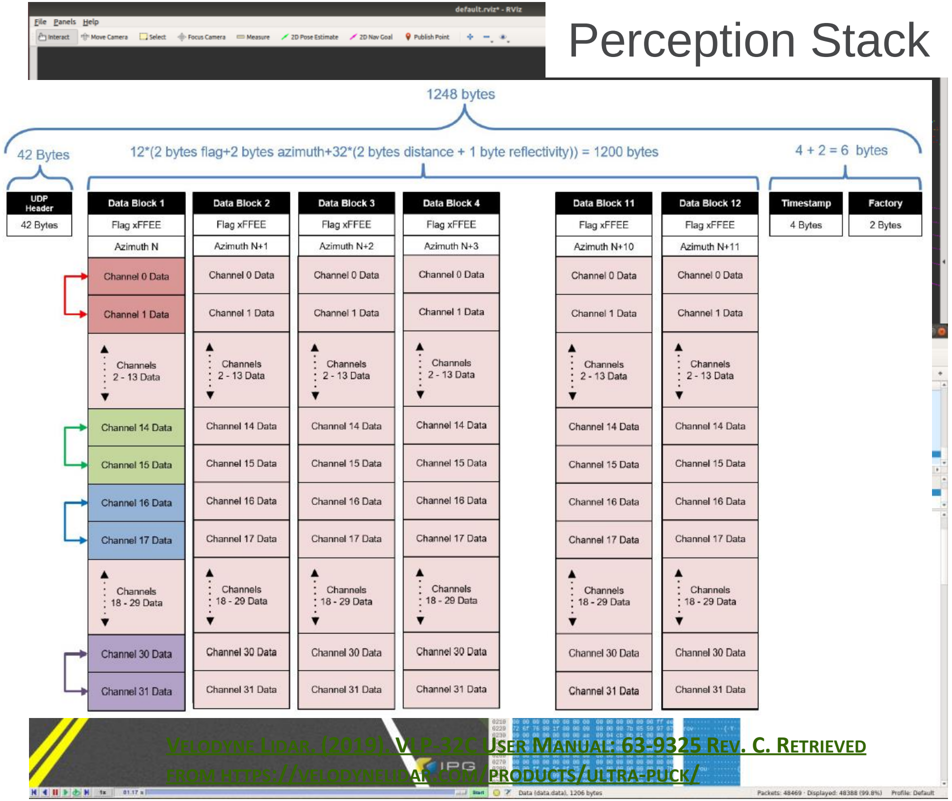


TECHNICAL ACCOMPLISHMENTS

Task 1.1: Lidar Integration

Perception Stack

- The simulated lidar sensor data is formatted to emulate the ethernet packet format detailed by Velodyne.
- The Velodyne ROS driver ingests the formatted data and makes it available to the ROS subsystem for control and visualization.

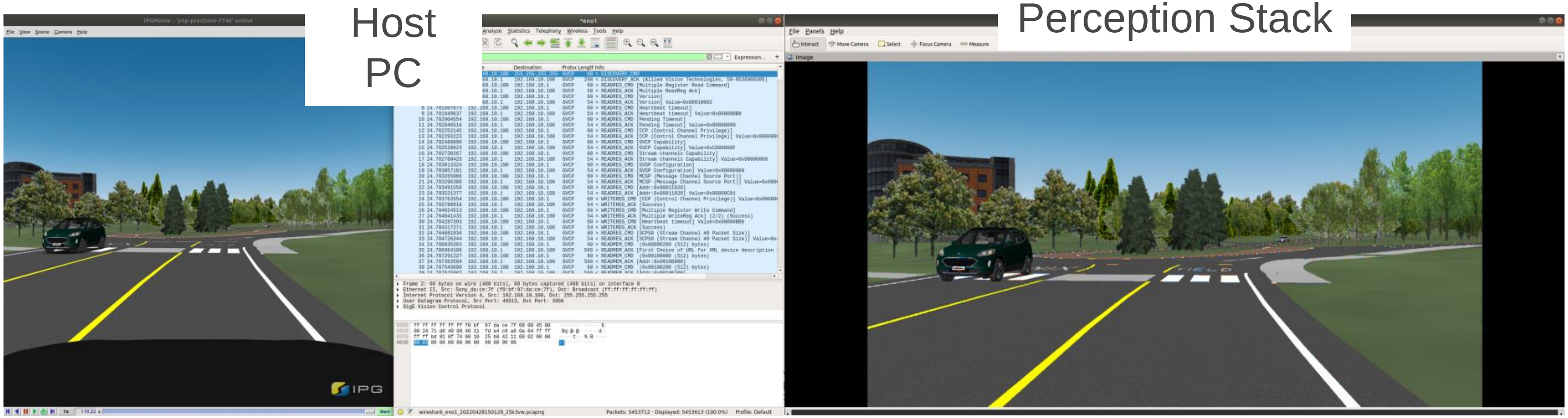


Velodyne Lidar. (2019). VLP-32C User Manual: 63-9325 Rev. C. Retrieved from https://velodynelidar.com/products/ultra-puck/

TECHNICAL ACCOMPLISHMENTS

Task 1.1: Camera Integration

- The simulated camera sensor data is formatted according to the GigE Vision Standard used by the Allied Vision cameras on the mule vehicle.
- The allied vision camera ROS driver ingests the formatted data and makes it available to the ROS subsystem for various control and visualization tasks.



TECHNICAL PROGRESS

Task 1.1: Vehicle and Perception Stack Integration

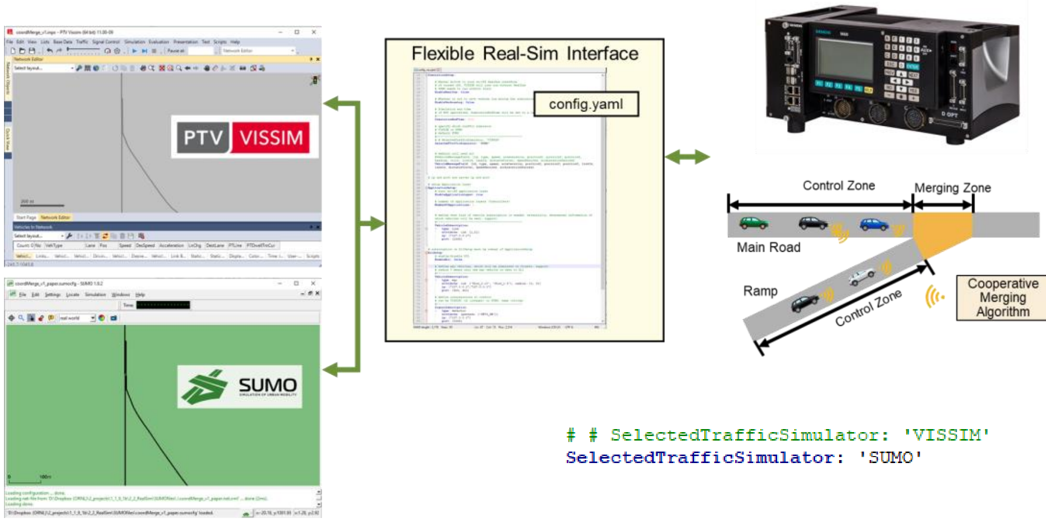
- Sensor Simulation and Emulation testing moved out of benchtop testing to in car integration on test mule.

- OPS-CAR (ORNL Platform for Senor and Control Autonomy Research)

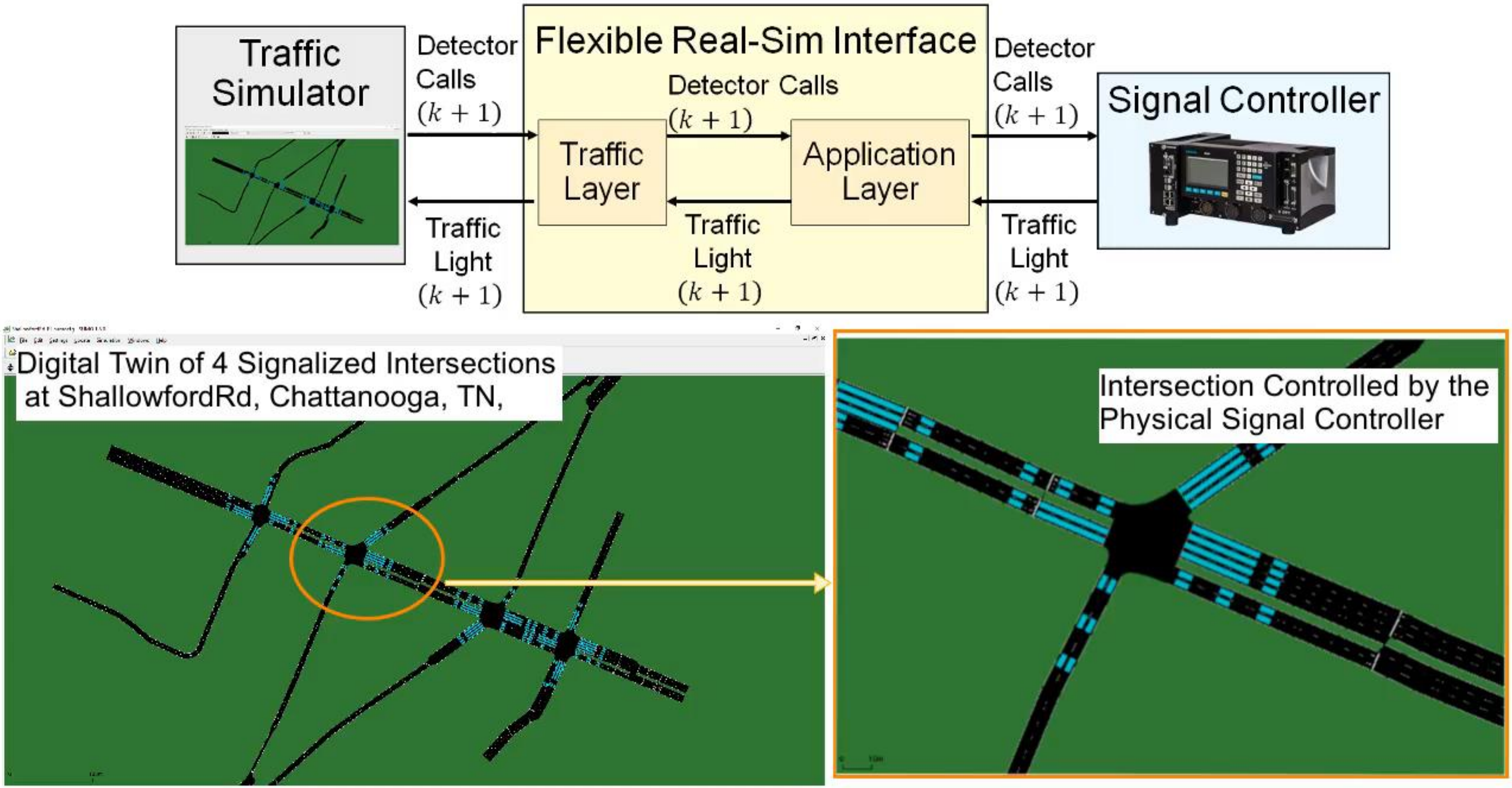
TECHNICAL ACCOMPLISHMENTS

Task 1.2: SPaT and traffic control XIL applications

- Real-Sim interface integration of both SUMO and VISSIM complete.
- A config.yaml file is used to specify options of Real-Sim interface and connections.
- Simply change one line in the config.yaml, users can now run same control algorithm and same traffic scenario in SUMO or VISSIM flexibly.
- We have tested using the cooperative merging application. More applications are under integration with the new Real-Sim interface, such as Tim's SMART speed and signal control, Hong's signal control.
- Simple integration with virtual environments is underway as well.




```
# # SelectedTrafficSimulator: 'VISSIM'
SelectedTrafficSimulator: 'SUMO'
```


Traffic Simulator
Detector Calls (k + 1)
Flexible Real-Sim Interface
Detector Calls (k + 1)
Traffic Layer
Application Layer
Detector Calls (k + 1)
Signal Controller
Traffic Light (k + 1)
Traffic Light (k + 1)
Traffic Light (k + 1)
Digital Twin of 4 Signalized Intersections at ShallowfordRd, Chattanooga, TN,
Intersection Controlled by the Physical Signal Controller

TECHNICAL ACCOMPLISHMENTS

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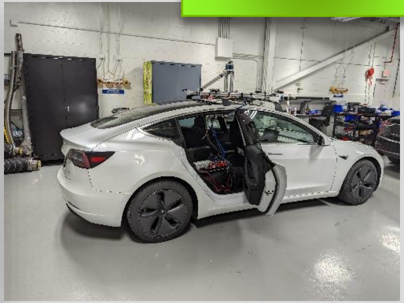
Task 1.3: Argonne Lab Perception and Connectivity Activity (ALPACA)

Argonne NATIONAL LABORATORY

Goal:
Capture ego vehicle operation and impacts on surrounding environment

APaCk-v



Argonne Perception and Connectivity kit
Vehicle

FY22 direct support of multiple SMART efforts
Real-Sim Task 2 - Digital Twin Development
EEMS096 (Light Duty Onroad Study)

Goal:
Collect infrastructure data, enable connectivity and experimental control

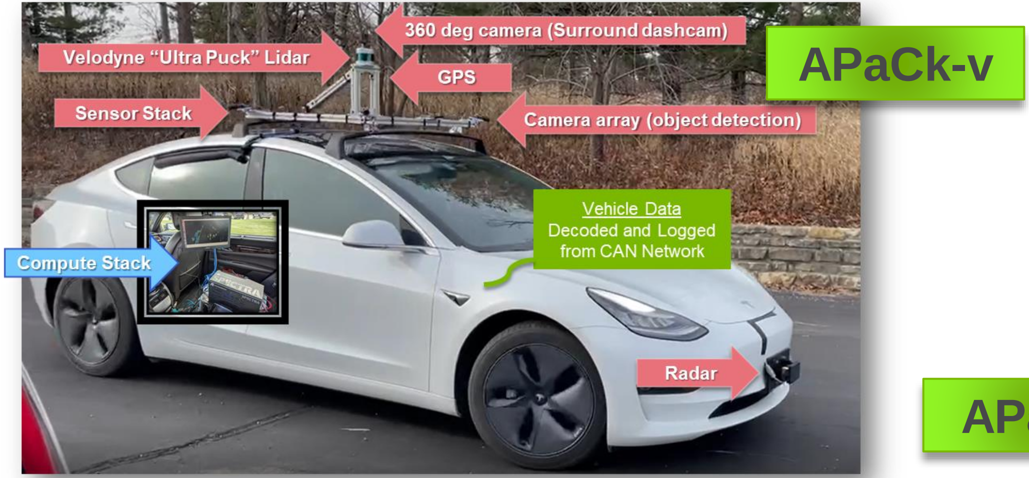
APaCk-i

Argonne Perception and Connectivity kit
Infrastructure

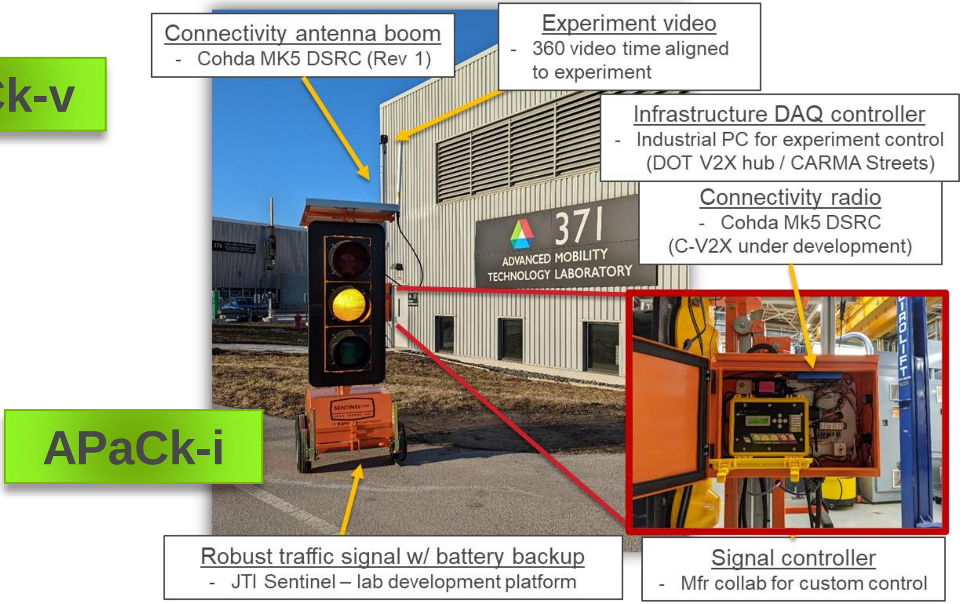
Supporting EEMS efforts in FY23/24
Cooperative Driving Automation (CDA) research

TECHNICAL PROGRESS

Task 1.3: Developed and Exercised Prototype ALPACA Platforms



- Transferable vehicle agnostic mounting
- Captures raw sensor OR summarized environment
- **Hardware overview**
  - Open Source (Autoware / ROS) compute stack
  - LIDAR / Camera (blurred) / Radar / Connectivity
  - Time aligned decoded vehicle data (CAN)

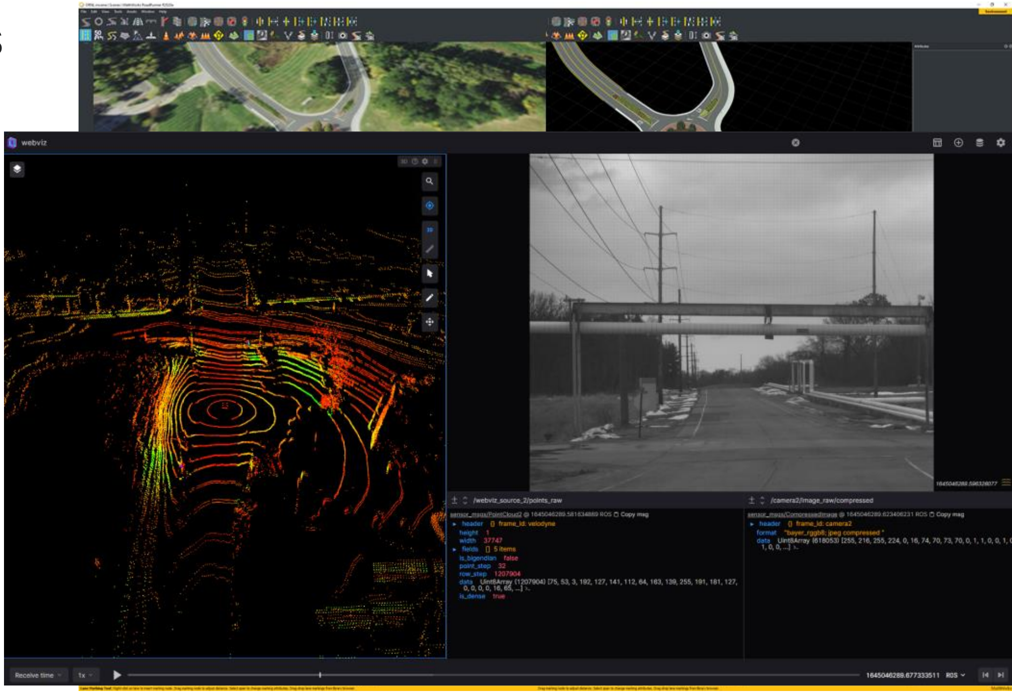


- Enables inf experiment control and data collection
- Portable base system for lab / field use, scalable to additional nodes

TECHNICAL PROGRESS

Task 2: Digital Twin Generation Plan Finalized

- Digital Twins of 4 EEMS Project Areas identified.
  - Chicago - Randal Rd.
  - Chattanooga - Shallowford Rd.
  - American Center for Mobility Test Track (Base DT Provided)
  - Tuscaloosa, AL (3 Intersections)
- 2 Options
  1. Manual Recreation using Data for Sensor Vehicles
  2. AI Based Auto Generation (Pilot test - Shallowford Rd. or Randal Rd.)



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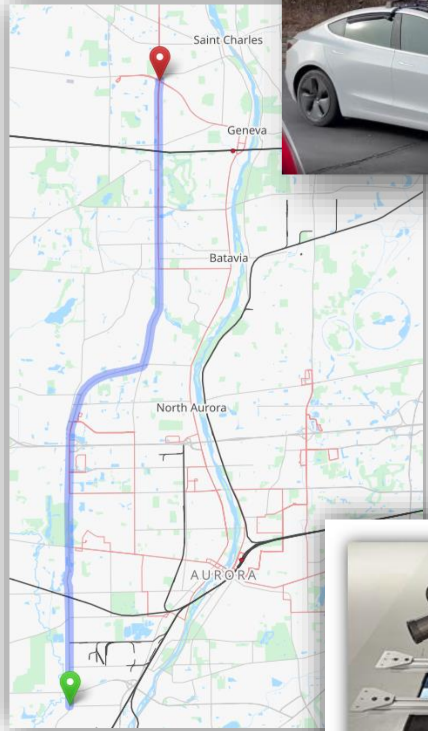
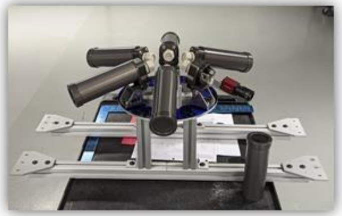
TECHNICAL ACCOMPLISHMENTS

Task 2: Digital Twin Generation

Preliminary data collection with ALPACA

- Preliminary dataset captured of Arterial Road
  - ~15 miles Orchard / Randall Rd in Kane County, IL
  - Roadway has active SPATs broadcast from infrastructure to cloud
- Preliminary data collected with APaCK-v on Tesla Model 3
  - Real-time face / plate blurring of all image data
  - Data collected to ROSBAG
    - Segment file size- 300-500 Gb
  - Direct data transfer for digital twin generation at ORNL
- APaCk-v revisions underway (Rev 2)
  - Improving camera viewing angles (full 360)
  - Extended use case through weatherproofing





TECHNICAL PROGRESS

Task 2: Shallowford Road Traffic Microsim DT Complete

- Calibrated MicroSim models and roadway DTs. Working on Virtual Environment next.

RESPONSE TO PREVIOUS YEAR REVIEWERS' COMMENTS

- The reviewer suggested that the researchers might want to reconsider the DSRC environmental data usage in light of the November 2020 FCC decision…
  - *Thank you for the feedback, the ORNL and ANL teams have both began moving to dual band systems for this reason. (DSRC and C-V2X capable)*
- …The reviewer further suggested that including an OEM as a partner could benefit the project by better defining OEM needs; while the primary purpose is not to meet OEM needs, it could provide valuable insight to the ORNL team.
  - *With the kick-off multiple other projects (for both ORNL and ANL), those new projects and this one have gained OEM support. Currently this team and other ORNL projects have 3 OEMs involved in various areas of this project.*
- The resources appeared sufficient to achieve the milestones from this reviewer's perspective. However, given that this project is on the "bleeding edge" of research, there is the potential for unforeseen challenges that could lead to the need for additional funding.
  - *The team could not agree more. Overall, the team has monthly meetings with the EEMS TM so we can discuss issues and progress so we can shift and pivot if needed. Whether that means changing focus, down scoping, or working with other projects in SMART or EEMS.*

PARTNERSHIPS AND COLLABORATIONS

Argonne NATIONAL LABORATORY	Primary project partner and contributor for Task 1.3 focused on the prototype DAQ unit for vehicles and infrastructure. This system is key for the completion of Task 2 and 3.
U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation	EEMS096, EEMS095, EEMS067, EEMS061
American Center for Mobility	Digital twin of ACM facility was provided to ORNL to allow for a digital twin to be generated and utilized. Additionally, data collected from ACM-led EEMS082 is provided to ORNL
IPG AUTOMOTIVE	IPG is collaborating with ORNL via software support for sensor modeling and emulation, as well as being a key partner is working with ROS and Autoware for XIL applications.

REMAINING CHALLENGES AND BARRIERS

- Though research facilities are open for experimentation, controls are in place to ensure safety during COVID-19 pandemic which impact worker productivity and operations. Reduced staff available onsite, in addition to the needs for social distancing, can make hands-on research and troubleshooting efforts challenging and more time consuming. Though no milestones or objectives are expected to be missed at this time, the possibility exists due to resource constraints. Creative methods for on-site and remote work will continue throughout limited, or reduced, site operations and the risk of impacts to project timing remain.
- Determining the computational requirements for these various applications is a major challenge as well as a barrier to some applications. To run the most demanding sensor simulations (i.e. lidar and radar) on HIL applications requires an extremely powerful PC to apply ray tracing techniques utilizing GPU calculation and a powerful real-time node.

PROPOSED FUTURE RESEARCH

Any proposed future work is subject to change based on funding levels.

- **Remainder of 2022**
  - Task 1.1/1.2 – Sensor, Sim, and XIL / Traffic Control
    - Switch from A-Stuff Delphi radar sensor and sensor model to OPS-CAR factory radar sensor and test emulation of new sensor on CAN network.
    - Physical traffic control stack covering 6-8 intersections (necessary to support the 1C project 1591) with physical and virtual C-V2X hardware.
  - Task 2 – Digital Twin
    - Complete DT for Chattanooga, Chicago, and Tuscaloosa locations.
- **Future FY 2023**
  - Task 1.1/1.2 – Sensor, Sim, and XIL / Traffic Control
    - IMU emulation and nail down computational limits when emulating sensors.
  - Task 3 – Validation of EEMS Projects
    - Run verification test with vehicles used on selected EEMS and SMART projects.

SUMMARY

Relevance

- The importance of the system of systems approach for understanding and managing vehicles equipped with ADAS, CAVs technologies, and their interactions with the surrounding traffic environments.
- Field experimentation captures ‘focused’ datasets lacking detail for detailed experimental analysis. Current connectivity implementations rely on large, fixed infrastructure investments.

Approach

- Task 1:
  - 1.1: Sensors - XIL and virtual environment 2.0.
  - 1.2: VPPG microtraffic 2.0
  - 1.3: AMTL Mobile DAQ
- Task 2: Real-Sim platform and digital twins
- Task 3: Validation using Current On-Road/Track EEMS Projects

Future Work

- Remainder of 2022
  - Task 1: Radar, traffic control stack, and V2X
  - Task 2: DT for Chattanooga, Chicago, and Tuscaloosa locations.
- Future FY 2023
  - Task 1: IMU emulation, sensor computational limitations, Real-Sim OSS Support
  - Task 3: Run verification tests.

Technical Accomplishments

- Task 1.1 – Sensors, Sim, XIL
  - Full Emulation of Camera/Radar/Lidar
- Task 1.2 – Traffic control/sim/XIL
  - XIL integration of Traffic Control Devices
- Task 1.3 – APaCk-i/v
  - Rev 1 and 2 Complete DAQ capabilities confirmed
- Task 2 – Digital Twins
  - Data collected for Randal Rd

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MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION

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TECHNICAL BACK-UP SLIDES

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TASK 1.1: SENSORS - XIL AND VIRTUAL ENVIRONMENT 2.0

- GPS/IMU/Fix proved to be much more difficult than expected, but also more realistic. Added geometrically accurate vehicle model for sensor placement.