JUNE 3-6, 2024

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

OAK RIDGE National Laboratory

Argonne NATIONAL LABORATORY

PROJECT OVERVIEW

Timeline

- Project Start Date: Oct. 2020
- Project End Date: Mar. 2024
- Percent Complete: 100%

Barriers

- Modeling and simulation environments are not all inclusive for different 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
  - FY 23: 1.23M

Partners

- Lead
  - Oak Ridge National Laboratory
- Partner
  - Argonne National Laboratory
- Collaborations
  - IPG Automotive
  - Ford Motor Company

OBJECTIVES AND RELEVANCE

- **Relevance:**
  1. Hardware-in-the-loop simulation for advanced driver-assistance systems (ADAS), connected and autonomous vehicle (CAVs) has grown increasingly complicated

  2. Validate ADAS and CAVs requires interactions with surrounding environments. However, field experiment often captures focused datasets that are not all encompassing.

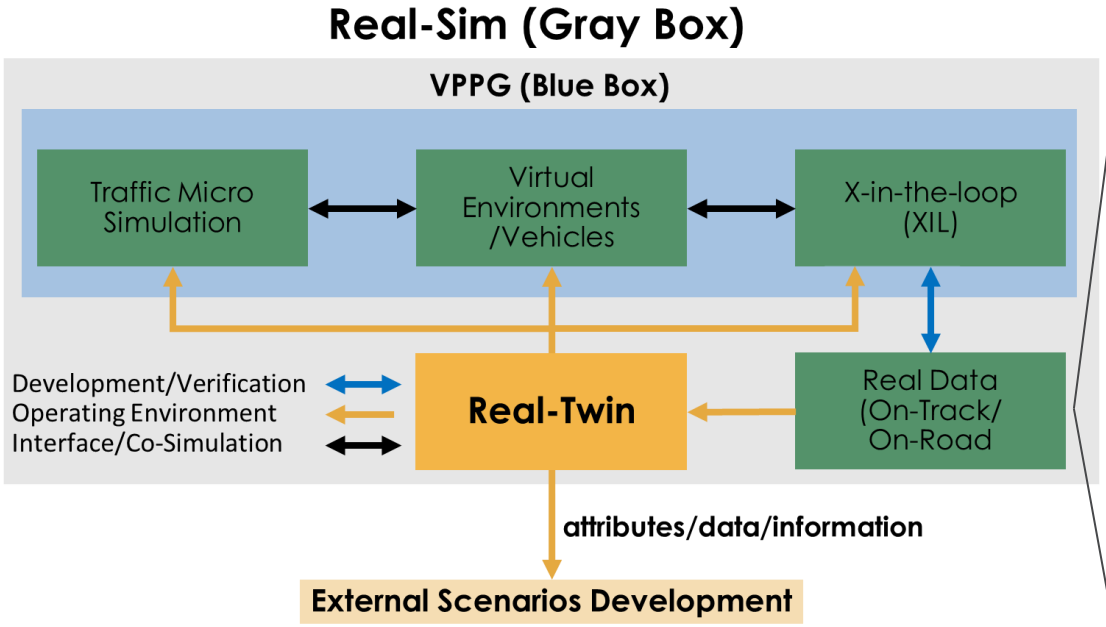
- **Objective:**
  1. The VPPG (Virtual Physical Proving Ground) Core-tools provide XIL with traffic simulation capability. Here we expand VPPG to incorporated a feedback loop and validation with ongoing EEMS/SMART projects utilizing Digital Twins.

  2. Bring in testing from a controlled, repeatable, inexpensive vehicle-infrastructure setup, that allows for large understanding of the environment through advanced testing platforms.

MILESTONES

Date	Milestone	Status
March 2023	Complete sensor emulation capability **(Task 1.1 ORNL)**	**Complete**
March 2023	Revisions to the Argonne Labs Perception and Connectivity kit- Vehicle, demonstrating improved localization, test management through a GUI, and data collection of traffic infrastructure data. **(Task 1.3 ANL)**	**Complete**
March 2023	Completed multi-layer digital twin of the Shallowford Rd Corridor, MLK Blvd., and McFarland Blvd. for simulation and HIL validation exercises. **(Task 2 ORNL)**	**Complete**
June 2023	APACK-V datasets captured for arterial and urban roadways in Greater Chicagoland area **(Task 2 ANL)**	**Complete**
Sept. 2023	Real-Sim interface (FIXS) deployment on GitHub. **(Task 1.2 ORNL)**	**Complete**
Dec. 2023	Build Simulink vehicle dynamics model to replace IPG CarMaker model and integrate with Carla co-simulation **(Task 1.2 ORNL)**	**Complete**
Dec. 2023	Refinement of the APACK-V for future use cases, including further development of our data QA pipeline and improved sensor synchronization **(Task 1.3 ANL)**	**Complete**
Mar. 2023	Validation of Real-Sim with EEMS projects (EEMS095, EEMS106, EEMS107) **(Task 3 ORNL)**	**Complete**

APPROACH



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

Sensors, micro sim, portable platform

- **Sensors - XIL and virtual environment 2.0.**
- **Enhances the traffic microsimulation capabilities to include SpaT, V2X, and traffic control**
- **Development of portable platforms (vehicle and infrastructure based) for V2X testing and data collection to enable XIL validation.**

Real-Sim platform and digital twins

- **Digital Twins to be created for support of this project and SMART 2.0/EEMS**
  - Chicago
    - Randall Rd.
  - Chattanooga
    - Shallowford Rd.
    - MLK Blvd.
  - Tuscaloosa, AL
    - McFarland Blvd.

Validation of the Real-Sim Platform

- **Validation of the Real-Sim Platform using Current On-Road EEMS Projects**
- **Projects that will support this effort.**
  - EEMS114
  - EEMS107
  - EEMS106
  - EEMS096
  - EEMS095
  - EEMS061

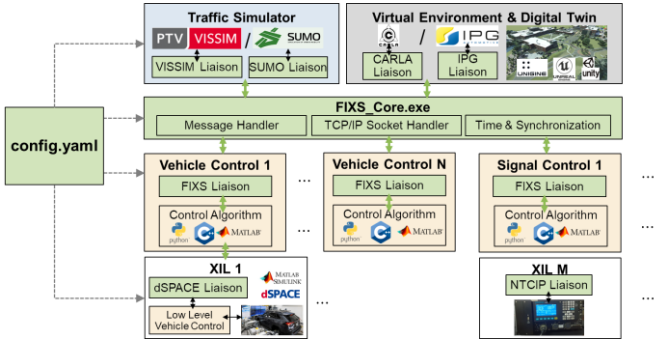
Green – subtasks from the last year

TECHNICAL ACCOMPLISHMENTS

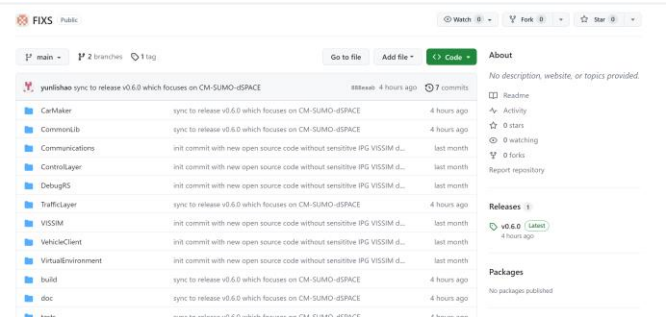
XIL Co-simulation 2.0

FIXS interface

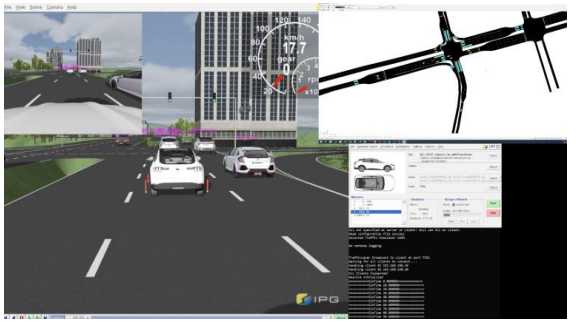
- The Real-Sim flexible interface for XIL simulation, FIXS, has been completed and released as an open-source tool on GitHub for the public.
- FIXS is actively being used to support other EEMS projects:
  - EEMS095 (ORNL,Smart2.0)
  - EEMS107 (UA,FOA)
  - EEMS106 (UTC,FOA)
  - ELT286 (Volvo,SuperTruck 3)
- FIXS is being maintained and improved



FIXS diagram



FIXS on GitHub



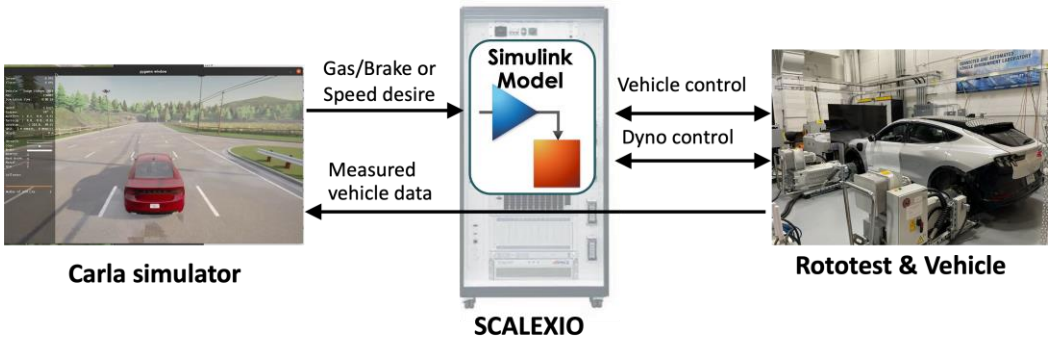
SUMO + IPG co-sim using FIXS

TECHNICAL ACCOMPLISHMENTS

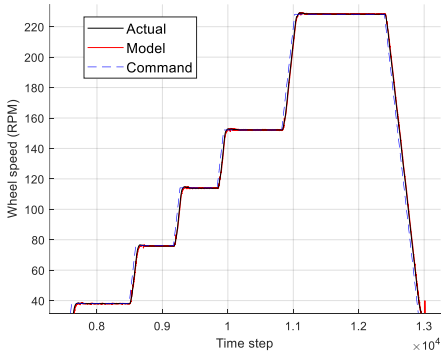
XIL Co-simulation 2.0

Carla-Simulink-Dynometer simulation

- In house developed Simulink vehicle model to replace IPG CarMaker.
- Carla provide photo-realistic environment for vehicle perception.
- Autonomous driving middle-ware like Autoware, can be integrated in this framework. And Carla – Autoware.universe co-sim has been tested.



Carla - VIL diagram



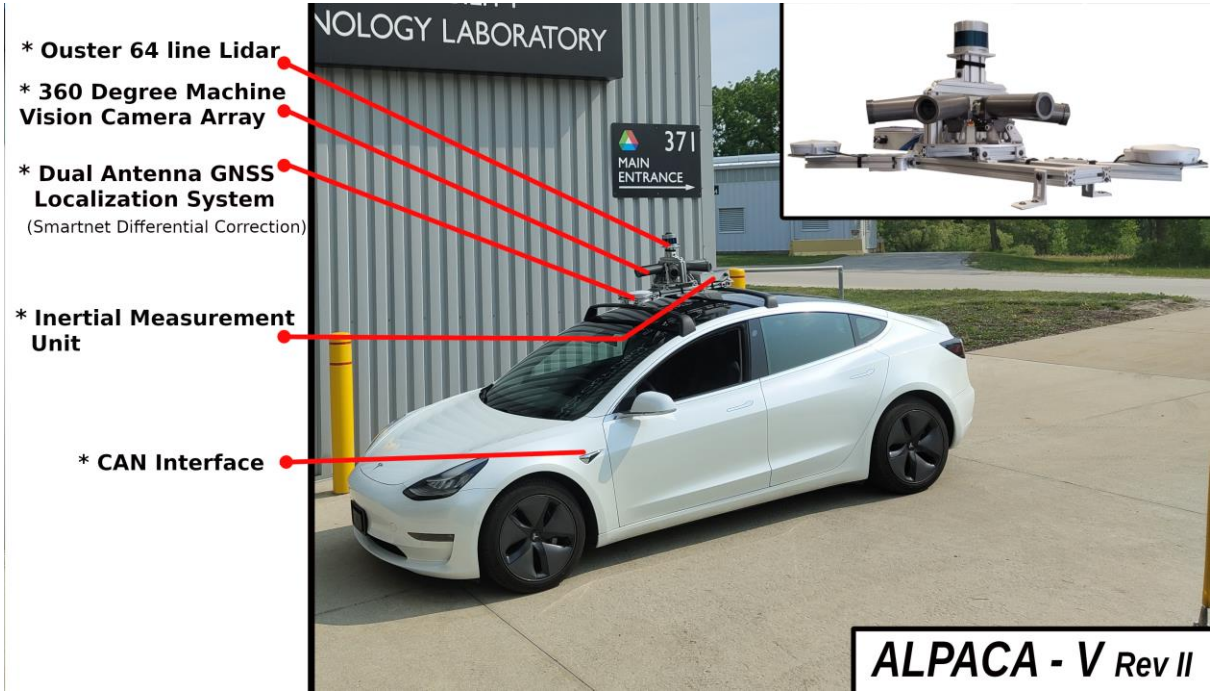
Dyno speed tracking

Driver's view of the experiment

TECHNICAL PROGRESS

Developed and Exercised Prototype ALPACA Platforms REV2

- Rev II of Transferable vehicle agnostic mounting
- Captures raw sensor OR summarized environment
- Localization capability
- High accuracy frame matching
- **Technical overview (New Features)**
- 360 Sensing / Capturing
- Real time Lidar/Vision Alignment (Raw collection)
- Differential GNSS/INS Localizer, Dual Antenna



TECHNICAL ACCOMPLISHMENTS

Argonne Lab Perception and Connectivity Activity (ALPACA-v)

FY23 direct support of multiple SMART efforts

- Real-Sim Digital Twin data collection
- EEMS096 (Light Duty On road Study)

FY23 Directly contributed to 2 open data-sets

- **Argonne Lab's Perception and Connectivity Activity Raw Sensor and Vehicle Data**
  - Available on Livewire Platform
  - Contains: Lidar, vision, trajectory and sensor information
  - Contain Trajectory quality analysis
- **Light-Duty Connected and Automated Vehicle Functionality in Real-World Operational Scenarios**
  - Available on Livewire Platform
  - Contains: Lidar, 360 Vision, GPS and CAN data.

TECHNICAL DEVELOPMENT

Argonne Lab Perception and Connectivity Activity (ALPACA-v rev3)

Update on Rev3 APaCk-V Platform (New features under-development)

- Stronger GPU + Updated Operating System
- ROS 1 → ROS 2
- Autoware.ai → Autoware.universe + Custom toolkits
- New **Dense Mapping Mode** with
- Task Specific Mission Module (Under development)
  - Stereo camera system + stereo SLAM
  - Fast environmental reconstruction capability (Realtime)

- **Expecting better performance and extended capabilities**

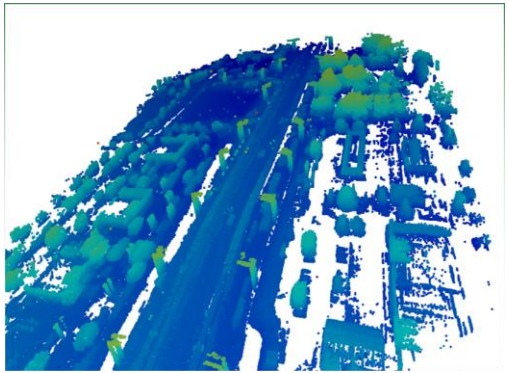
* A sample of dense-point-cloud map processed from test data-set

TECHNICAL PROGRESS

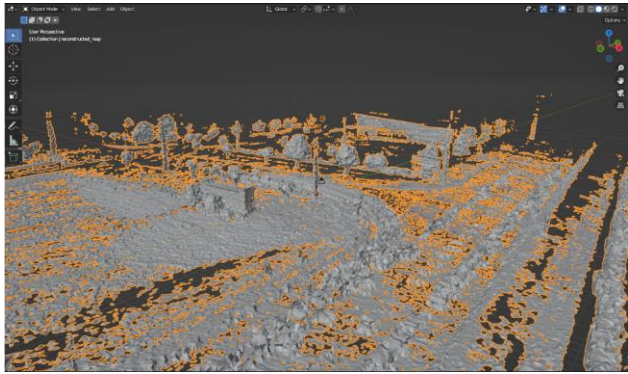
Digital twin of Randall Rd.

Utilizing the data collected from the portable platform ALPACA-v, the digital creation of Randall Rd is in progress. This will be a continuing task as part of RealSim-RealTwin Deployment project.

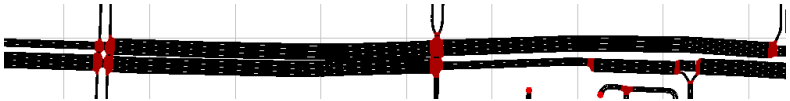
- Modeled as a 3d surface reconstruction from clip of pointcloud data
- Exploring reconstruction algorithm like opensource SoTA
- Road network file will be generated by Real-Twin tool.



Registered PointCloud map From lidar data collected by ALPACA-v



Reconstructed mesh using the PointCloud

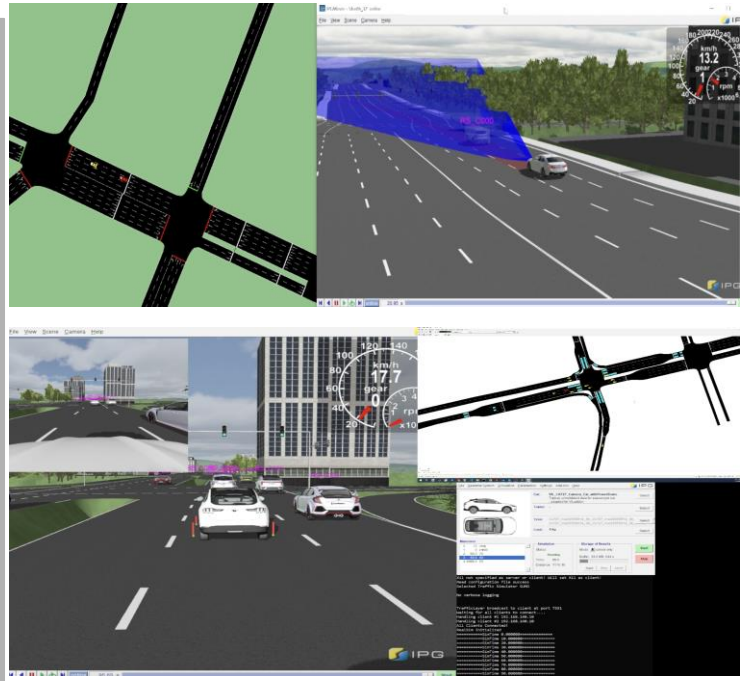


Road network generated for SUMO using Real-Twin tool chain for Randall Rd (partially shown)

TECHNICAL PROGRESS

Task 3: Validation of Real-Sim with EEMS projects

- Compare EEMS095 (Integrated Control of Vehicle Speeds and Traffic Signals for Reducing Congestion and Energy Use) project team's on-road data and CAVE Lab testing results. (Upper right figure)
  - Recorded real-world data including Lead/Ego vehicle and SPaT info are reproduced in SUMO+IPG environment using FIXS interface.
  - Repeatable, controllable experiment were conducted to compare energy consumption between different driving model
- Supporting EEMS106 and EEMS107 project, validate ego vehicle energy consumption with real traffic flow. (Lower right figure)
  - Real traffic data captured by UA team and UTC team reproduced in SUMO/VISSIM + IPG environment
  - Compare ego vehicle energy consumption under different
    - traffic flow
    - signal control algorithm



SUMO IPG co-simulation

PARTNERSHIPS AND COLLABORATIONS

Argonne NATIONAL LABORATORY	**Primary project partner and contributor for Task 1.3 focused on the prototype ALPACA 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	**EEMS114, EEMS107, EEMS106, EEMS096, EEMS095, EEMS067, EEMS061**
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.**
Ford	**ORNL and Ford is currently under a CRADA that exercises Real-Sim capabilities for simulation and XIL testing, which provides critical feedback to the project.**

REMAINING CHALLENGES AND BARRIERS

- In FY23, reduced staff and changing of project PI slow down the XIL testing schedule, as well as the digital twin creation of the Randall Rd. The digital twin creation will be continued in Real-Sim/Real-Twin Deployment project.
- Compare with the commercial solution (IPG CarMaker), the in-house built vehicle Simulink model needs to be tuned to have better driving performance on the dynometers.
- When doing co-simulation using FIXS for SUMO/VISSIM with IPG CarMaker, a better driver is needed to replace IPG default driver, as the IPG driver may miss detect the lead vehicle, causing unexpected behavior for ego vehicle.

PROPOSED FUTURE RESEARCH

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

- **Remainder of 2024**
  - Validation of EEMS Projects
    - Continue support two FOA projects - EEMS106, EEMS107
- **Future research and development**
  - Scaling up Real-Sim framework:
    - Support multiple high-fidelity clients/models in co-simulation with larger scale scenario
    - Support additional vehicle/3D simulators
    - Support V2X communication in Real-Sim framework
    - Support validation of autonomous driving feature
  - XIL Automation:
    - Scenario synchronization within Real-Sim framework.
    - Safety check and validation for VIL experiments

SUMMARY

Relevance

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

Approach

- Sensors, micro sim, portable platform
  - Sensors - XIL and virtual environment 2.0.
  - VPPG XIL co-simulation 2.0
  - ALPACA Mobile DAQ
- Digital Twins to be created for support of this project and SMART 2.0/EEMS
- Validation using Current On-road EEMS Projects

Summary

- The Real-Sim project has finished all milestones and meet all the goals. The major highlights of this year's work are:
  - Deploy FIXS on GitHub for public
  - Built and tested Simulink vehicle dynamics model to replace CarMaker model and integrate with Carla co-simulation
  - Refinement of the APACK-V for future use cases, including further development of our data QA pipeline and improved sensor synchronization
  - Validation of Real-Sim with EEMS projects has been completed for EEMS095, and In progress for EEMS106, EEMS107

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MOBILITY FOR OPPORTUNITY

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