JUNE 12-15, 2023

REAL-SIM

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PROJECT ID: EEMS101

PROJECT OVERVIEW

Timeline

- Project Start Date: Oct. 2020
- Project End Date: Dec. 2023
- Percent Complete: 80%

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. 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.)

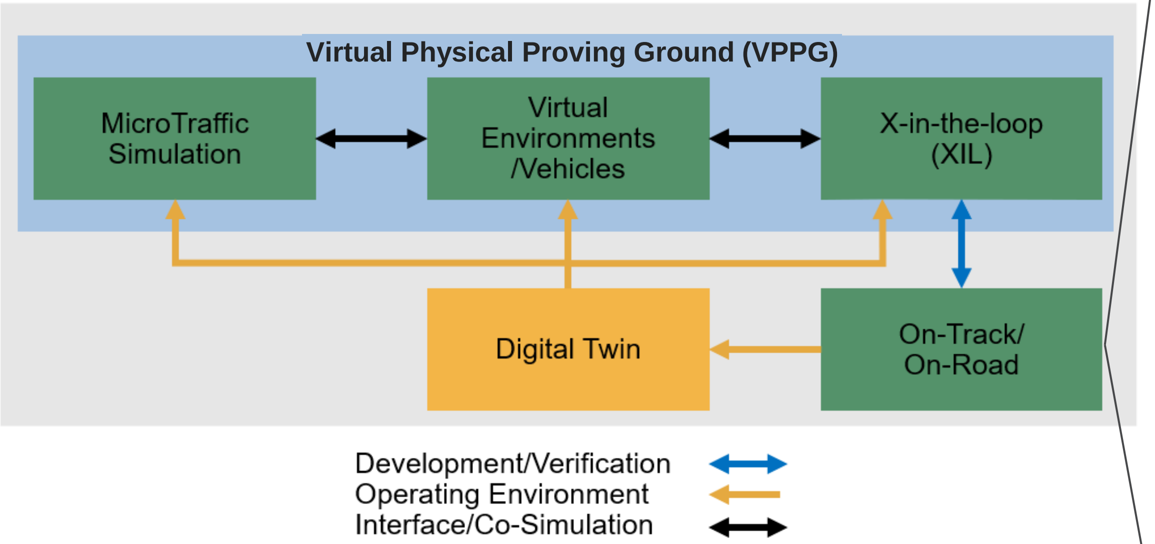
- **Objective:**
  1. Expand the capabilities of the Virtual Physical Proving Ground (VPPG) Core-tools project feedback loop to include digital twins (DTs) as well as greater real-world correlation by utilizing on-road data in a closed-loop process for validating performance of different controls in simulated 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 2023	Complete radar 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)**	**On Track**
Sept. 2023	Real-Sim interface deployment on GitHub. **(Task 1.3 ANL)**	**On Track**
Dec. 2023	Validation of Real-Sim with EEMS projects (EEMS095, EEMS106, EEMS107) **(Task 3 ORNL)**	**On Track**

APPROACH

Real-Sim

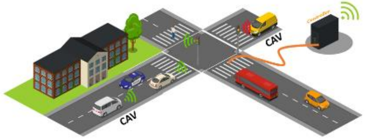


Develop a mobile connectivity-enabled platform to coordinate and capture on-road experimentation

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 XIL co-simulation 2.0.**
- **Subtask 1.3: Development of portable platforms (vehicle and infrastructure based) for V2X testing and data collection to enable XIL validation.**

Task 2

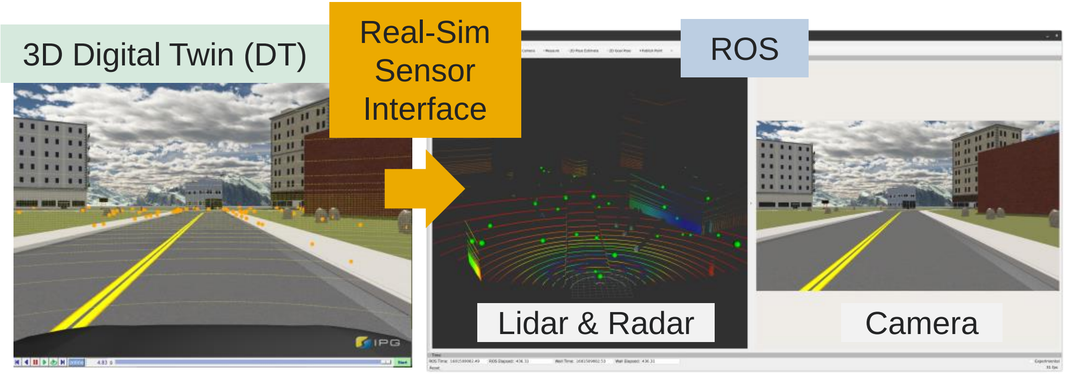
- **Task 2 – Real-Sim platform and digital twins**
  - **Digital Twins to be created for support of this project and SMART 2.0/EEMS**
    - Chicago
      - Randal Rd.
    - Chattanooga, TN
      - Shallowford Rd.
      - MLK Blvd.
    - Tuscaloosa, AL
      - McFarland Blvd.

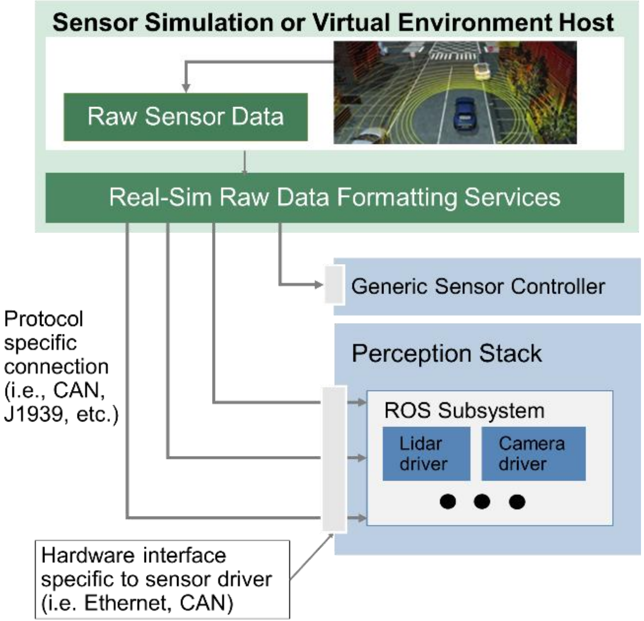
Task 3

- **Task 3 – Validation of the Real-Sim Platform using Current On-Road EEMS Projects**
- **Projects that will support this effort**
  - EEMS095 SMART 2.0 integrated speed and signal control
  - EEMS106 UTC FOA eco-signal control
  - EEMS107 UA FOA network signal optimization

TECHNICAL ACCOMPLISHMENTS

Task 1.1: Sensor Emulation

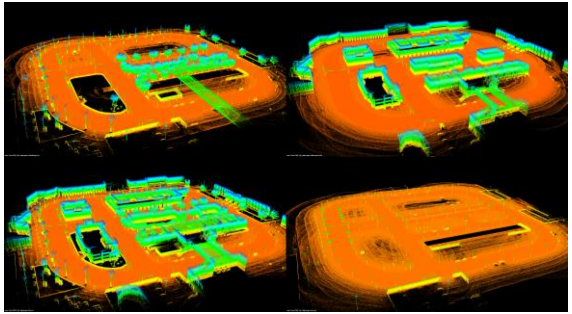


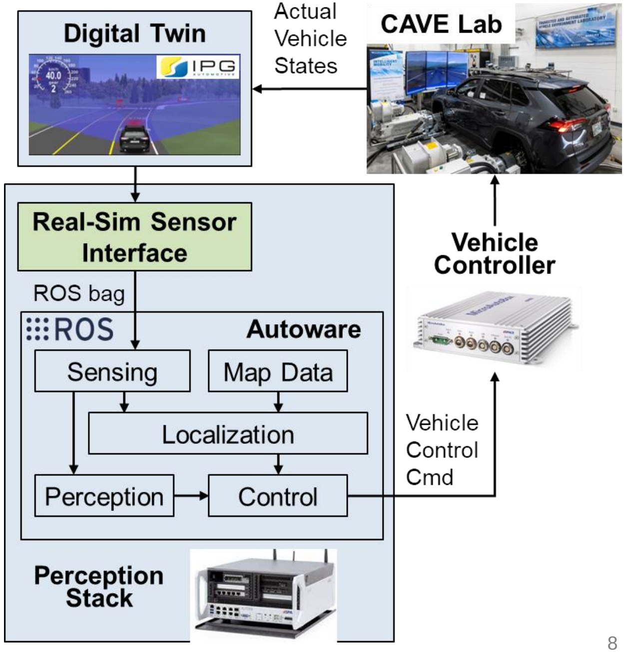


- The sensor streams are formatted based on physical sensors. So the platform will be able to immerse a vehicle into a virtual environment by simulating the vehicle sensors in a virtual environment (3D Digital Twins) and streaming emulated raw data streams to the actual on-vehicle perception stacks and controllers.
- Support camera, lidar & radar sensor streaming.

TECHNICAL PROGRESS

Task 1.1: How real is real?



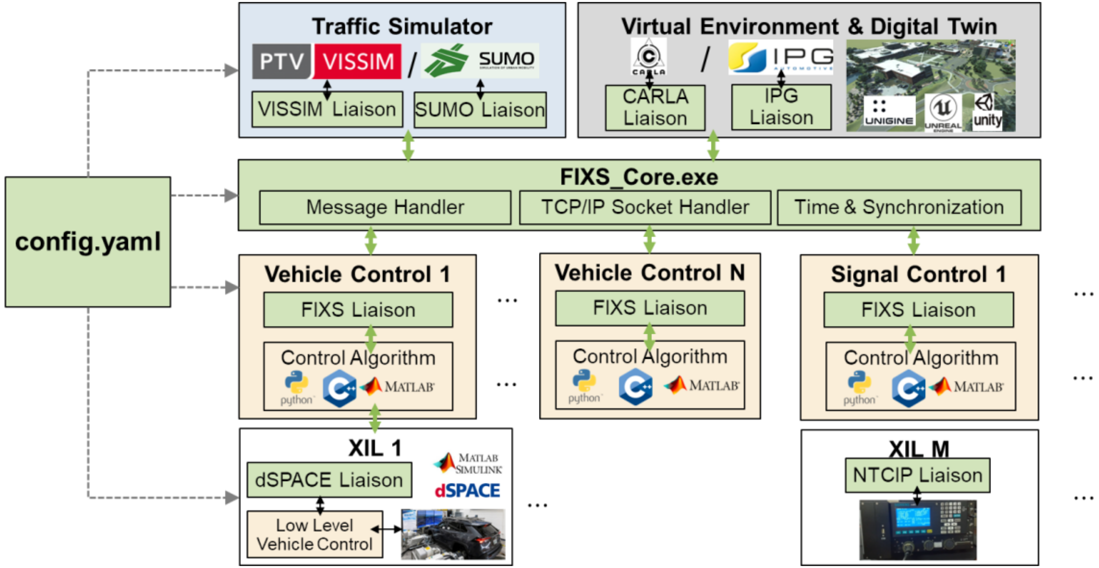


- 3-stage of comparison in progress:
  - Localization using HD point cloud in DTs with different levels of details.
  - Autonomous driving control in DTs with different levels of details.
  - Performance of vehicle on XIL in DTs versus on-road vehicle data.

TECHNICAL PROGRESS

Task 1.2: XIL Co-simulation 2.0

- Real-Sim flexible interface for XIL simulation (FIXS) supports co-simulation of VISSIM/SUMO, IPG 3D DT, XIL with actual vehicles and signal controllers.
- A config.yaml file is used to specify options of co-simulation and connections.
- Connections are handled internally using TCP/IP and are transparent to the user.
- Current focus:
  - Co-simulation in Carla
  - Liaison for Python script
  - Performance boost for potential scale-up



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TECHNICAL ACCOMPLISHMENTS

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

Argonne NATIONAL LABORATORY

Goal:
Collect infrastructure data, enable connectivity and experimental control

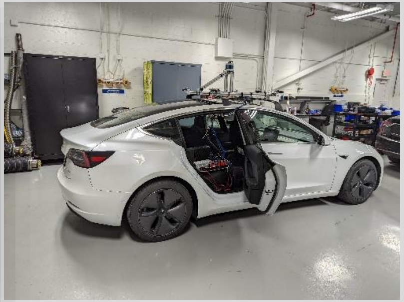
APaCK-I

Argonne Perception and Connectivity Kit-
Infrastructure

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

Goal:
Capture ego vehicle operation and impacts on surrounding environment

APaCK-V



Argonne Perception and Connectivity Kit-
Vehicle

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

TECHNICAL PROGRESS

Task 1.3: APaCK-I

Goal- ***Enable flexible, customizable experimental testing on-road with traffic infrastructure components with real-time I2V connectivity***

- Developed scalable, flexible architecture
  - Dynamic Signal Phase & Timing (SPAT) control from traffic signal manufacturer collab (John Thomas Inc)
  - Map creation for any desired roadway (ANL rad for POC)
  - Connectivity (DSRC / C-V2X) through DOT CARMA Streets integration
  - Result- Quick deployment of connected nodes for closed road experiments of CAVs
- Successful demonstration with APACK-V equipped vehicle
- Upcoming deployment in DOE Cooperative Driving Automation (CDA) activities.

TECHNICAL PROGRESS

Task 1.3: APaCK-V

Argonne NATIONAL LABORATORY

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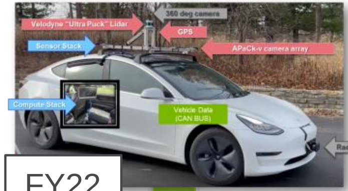
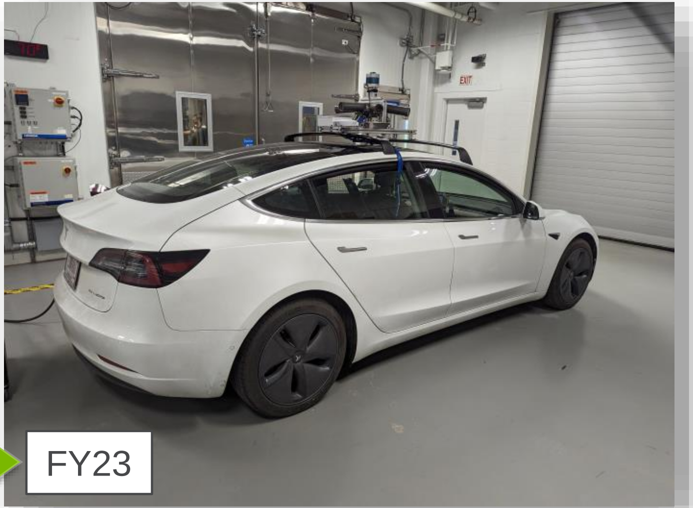
Goal- ***Development and deploy a research flexible system for high-fidelity on-road data collection of vehicles & their environment***

Past year system deployments

- **SMART2.0 Real-Sim RAW data collection**
  - **Greater Chicagoland mapping in FY23**
- **SMART2.0 light duty on-road summarized data**
  - **Tesla Model 3 with Full Self Driving**



FY22



FY23

FY23 Key Revisions

- **Sensor Array**
  - Revised mounting structure
  - Full 360 camera array
  - Weatherproof construction
  - Improved localization (Novatel
  - Updated LIDAR (Ouster OS1-128)
- **Compute**
  - Integrated image data collection (Gopro prior)
  - Improved face/plate blurring
  - Real-Time SPAT log from supported roads (TTS)
  - Integrated raw/decoded vehicle data (CAN)
  - Other improvements:
    - Independent power (no added vehicle load)
    - GUI with revised driver interface & controls
    - ROS 2 / Autoware Auto integration
- Datasets deployed to DOE researchers via Livewire

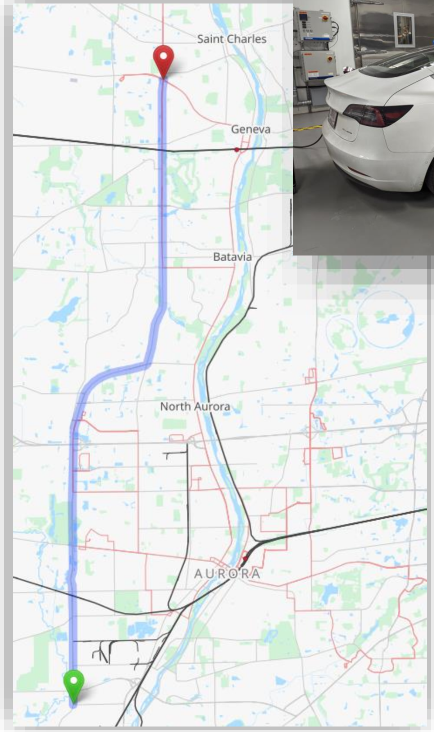
TECHNICAL ACCOMPLISHMENTS

Task 2: Digital Twin Data Capture

--Greater Chicagoland

- Datasets captured in past FY for DT generation
  - Preliminary dataset captured in May 2022, ~15 miles Orchard / Randall Rd in Kane County, IL
  - Supplemental datasets captured during Summer 2022

- Refined datasets collected with APaCK-V Q1-Q3 FY23
  - Real-time face / plate blurring of all image data
  - Refined dataset with higher fidelity RTK GPS, improved camera placement, and higher resolution LIDAR
  - Multiple roadways to be captured (Urban / arterial / interstate)
  - Varying time of day for traffic variability

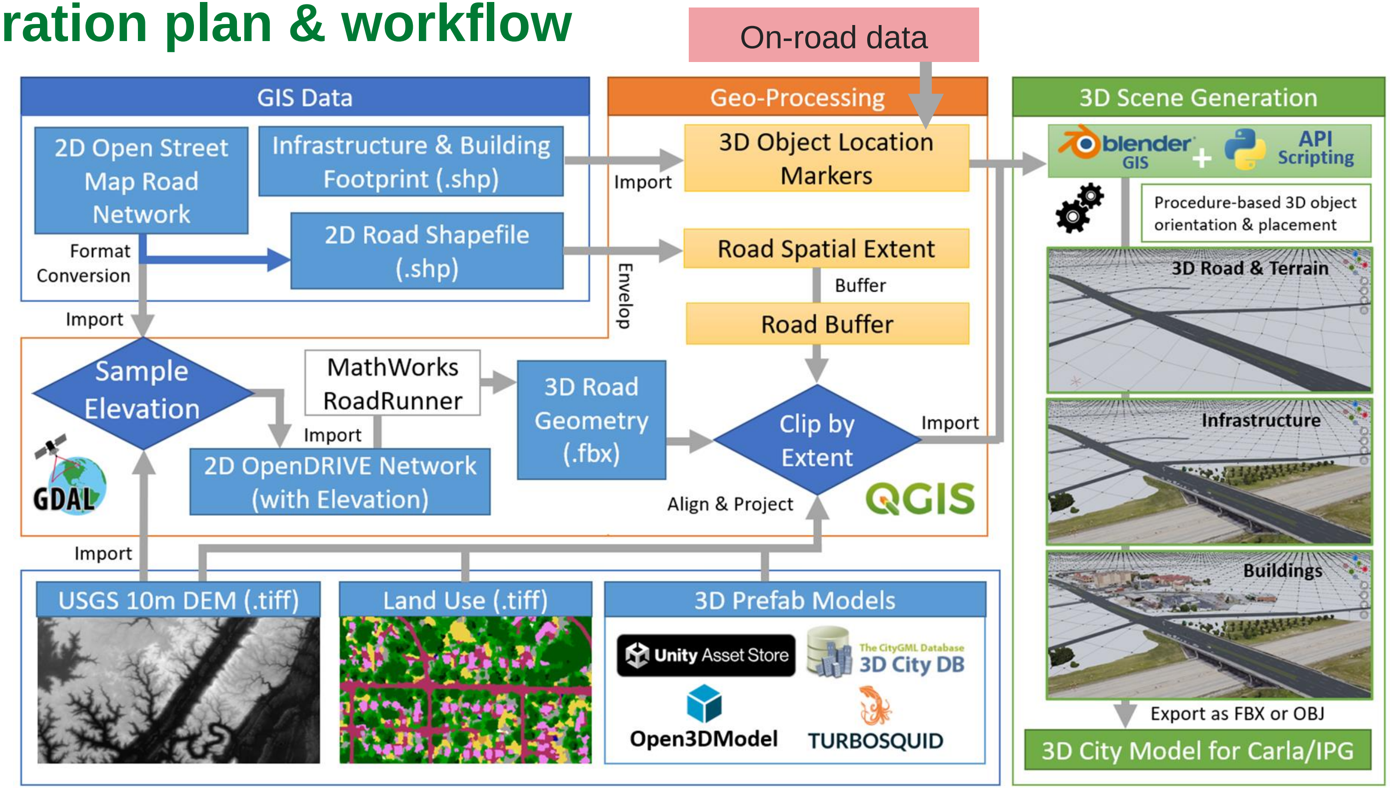


Kane County corridor data captured, more roadways underway

TECHNICAL PROGRESS

Task 2: DT generation plan & workflow

- Cover 4 EEMS projects areas:
  - Shallowford Rd., TN
  - MLK Blvd., TN
  - McFarland Blvd., AL
  - Randal Rd., IL
- 2 data sources:
  - Existing databases and GIS data (e.g., Google, USGS)
  - On-road data: manually or AI based auto generation



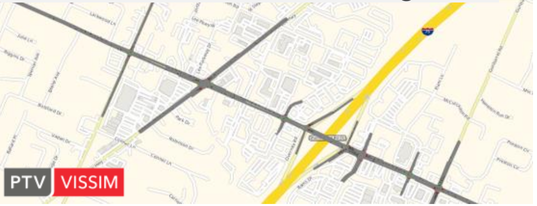
TECHNICAL ACCOMPLISHMENT

Task 2: DT of MLK Blvd., Shallowford Rd., McFarland Blvd.

- Calibrated traffic microsim and 3D digital twins, exportable to Carla/IPG


MLK Blvd., Chattanooga, TN



Shallowford Rd., Chattanooga, TN



McFarland Blvd., Northport, AL


Task 3: XIL testing for MLK Blvd. and Shallowford Rd. in progress

RESPONSE TO PREVIOUS YEAR REVIEWERS' COMMENTS

- …Barriers related to computational expense appear to be partly addressed at this point since simulations are operational; however, it appears more insights to the specific balance of computational power versus expense and research value could be a supplementary task within this project…
  - *Thank you for the feedback. In this FY, the project team has started the evaluation of how digital twins (DTs) with different levels of details will affect XIL evaluation for different mobility technologies. We aim to identify the "minimum" set of DT elements/3D objects needed for different applications to simplify the DTs and reduce computational burdens.*
- …It is not entirely clear how "all" scenarios will be addressed by the current research efforts without an incredibly large data storage and testing infrastructure, but the current effort does appear to provide some much-needed supplementary data…
  - *Thank you for the feedback. The "minimum" set of DT elements/3D objects (see previous comment) can help reduce the amount of data needed. Also, the ORNL PI has another project (EEMS114: Real-Twin) that tackles the question "what are the relevant scenarios to different mobility applications". Tools developed from EEMS114 can help automatically create a large variety of scenarios to avoid storing large amount of data.*
- …it is a bit confusing about what "multi-layer digital twin" means in this project. Does it refer to "traffic layer" (traffic signal control in SUMO) and "application layer" (physical traffic signal controller)?
  - *The DTs refers to the simulated real-world scenarios in both traffic microsimulation (SUMO/VISSIM) and vehicle simulators (CARLA/IPG). These two types of simulators have different requirements on DTs even when the same real-world scenario is replicated. So multiple layers of DTs are needed for different simulators.*

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 Real-Twin, EEMS107 UA FOA, EEMS106 UTC FOA, EEMS095 Integrated speed & signal control, EEMS067 Virtual Physical Proving Ground, EEMS061 Regional Mobility CTwin
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

- **Scheduling** is a major factor as XIL testing in Connected and Automated Vehicle Environment (CAVE) Lab is an important portion of this project, but it is also the most desired resource for many projects. It is important to have frequent and open communication to better coordinate different projects. In busy times, multiple shifts of CAVE lab operation throughout a day may be needed.
- The Real-Sim approach integrates many open-source/commercial simulation software in XIL through individual software APIs. **Compatibility** is a concern when a new software version releases which can change behaviors of APIs and software. It is important to continue partnership with these software companies to communicate our usages to ensure better compatibility or at least be well informed before any major software change happens.
- 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 2023**
  - Task 1.1/1.2 – Sensor, Sim, and XIL / Traffic Control
    - Fully integrate sensor emulation and XIL with Carla
    - Refine Real-Sim XIL interface and release as an open-source XIL toolchain for mobility studies
  - Task 2 – Digital Twin
    - Data collection for digital twin of Greater Chicagoland Roadways taking place during Spring 2023
  - Task 3 – Validation of EEMS Projects
    - Exercise Real-Sim on experimental validation for 1) EEMS095 SMART 2.0 integrated speed and signal control, 2) EEMS106 UTC FOA eco-signal control, 3) EEMS107 UA FOA network signal optimization
    - Run verification test of Real-Sim XIL with on-road vehicle testing in EEMS095: SMART 2.0 integrated speed and signal control

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

- Task 1:
  - 1.1: Sensors - XIL and virtual environment 2.0.
  - 1.2: VPPG XIL co-simulation 2.0
  - 1.3: Argonne Labs Perception and Connectivity Activity (ALPACA)
- Task 2: Real-Sim platform and digital twins
- Task 3: Validation using Current On-road EEMS Projects

Summary

- The Real-Sim project is making great progress towards the overall goals and milestones. The major highlights of this year's work are:
  - Fully operation raw sensor emulation of various vehicle perception sensors including lidars, radars, cameras. This allows for a given test vehicle to operate based on simulated virtual environments in a laboratory or on-road/track.
  - The flexible interface for XIL simulation (FIXS) is developed as an open-source tool to enable plug-in-and-play co-simulation of VISSIM/SUMO, IPG/Carla, XIL with actual vehicles and signal controllers.
  - ANL’s APaCK-I/V units are actively in-use on-road, supporting advanced data collection efforts for digital twin creation and dataset generation in EEMS096: Characterizing CAVs, sensors and connectivity
  - A streamlined workflow is established to create digital twins using on-road data and existing databases.

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MOBILITY FOR OPPORTUNITY

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