MODELING, SIMULATION, PROTOTYPING & VALIDATION

ACCELERATING AUTONOMOUS VEHICLE DEVELOPMENT AND EVALUATION WITH THE VANE SIMULATION TOOL SUITE

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Limitations of Physical Testing and Evaluation (T&E) for Autonomy Development

Time

- Many developers may have months with only a handful of prototypes
- Testing centers only have weeks

Money

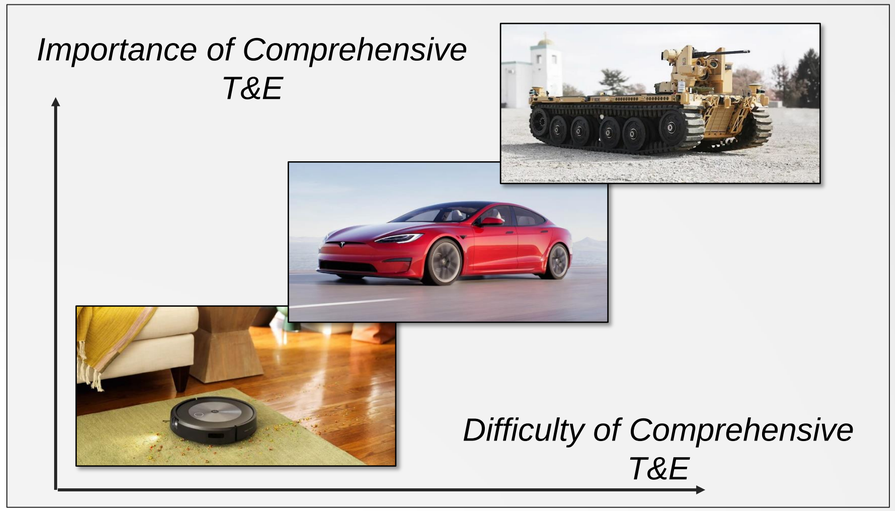
- Traditional T&E regimes can cost millions
- Autonomy requirements still being developed

Control

- Unable to control physical elements
- Tests have limited repeatability and narrow operational applicability

Risk

- Exploring behavior in dynamic environment (e.g. pedestrians, traffic, wildlife) is dangerous
- Damage to exquisite platforms during testing can delay completions



Testing like this is insufficient …

… if this is where you operate.

Importance of Modeling & Simulation for Autonomy Development

Utility

- Enable virtual prototyping
- Augment physical testing and evaluation
- Explore edge cases and failure modes
- Save money and time while reducing risk
- Inform Tactics, Techniques and Procedures (TTPs)

Hypothetical UxV system(s)

Physical Experiments

Modeling & Simulation

UGV development, testing, and evaluation: match tasks with best m

- Standard mobility metrics
- Hardware control validation
- T&E of By-Wire and Active Safety systems
- Environment impact on sensor hardware (*not perception*)
- Final system validation

- Sensor jamming / interference
- Communication between system components
- Soldier training
- TTP demonstrations

- System prototyping
- Autonomy reaction to dynamic obstacles
  - Pedestrians
  - Vehicles
- Effects of incremental environment conditions
  - Rain, dust, snow, etc.
- Dense urban operations
- Mission-level, cross-country operations
- Sensor placement optimization
- Analyze swarm behavior
- Algorithm training (i.e. synthetic data)
- Edge case analysis
- …

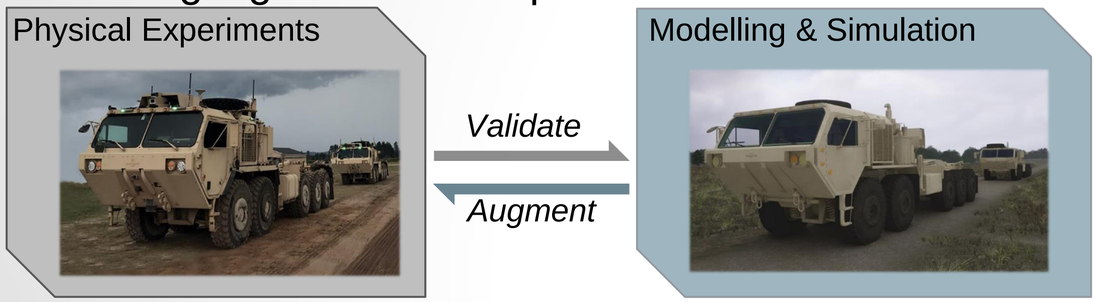
Virtual Autonomous Navigation Environment (VANE)

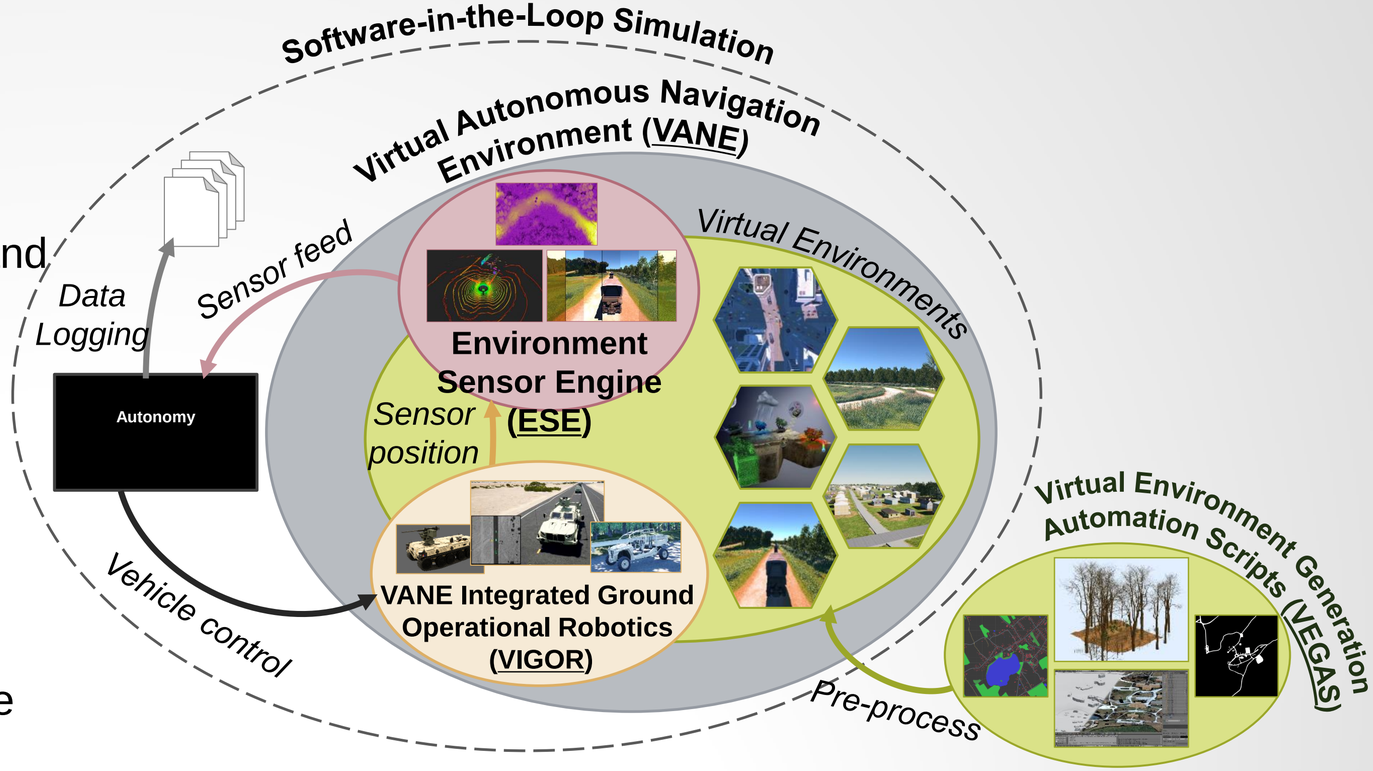
Description

- Is a suite of tools that are modular, extensible, and distributable to DoD
- Provides both real-time and high-fidelity simulation capabilities for ground vehicles (wheeled or tracked) and sensors
- Supports the full robotics development cycle
- Allows virtual evaluation of sensors and autonomous vehicles in various environmental conditions

Example Use Cases

- Developing or evaluating autonomy
- Determining ideal sensor placement/requirements
- Generating labeled, synthetic training data for machine learning algorithm development





VANE configuration for autonomy SIL use case

Virtual testing of sensors and autonomous vehicles in various environmental conditions to augment physical testing and ensure a robust system while saving time and money

VANE Simulation Component: VIGOR Vehicle Models

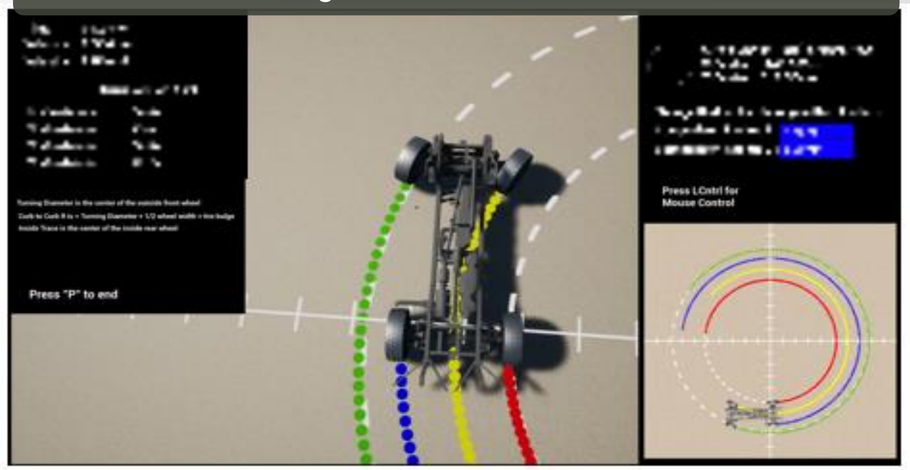
Vehicles-Terrain Interaction Validation

- Virtual vehicle performance metrics determined with VIGOR implementations of standardized vehicle tests:
  - Acceleration, NATO double lane change, braking, steering, ride-shock, etc.
- Vehicle models calibrated by comparing virtual test data with production verification test reports
- Terrain properties based on mobility metrics from ERDC field test data
- Lumped parameter models used for vehi[illegible]n speed

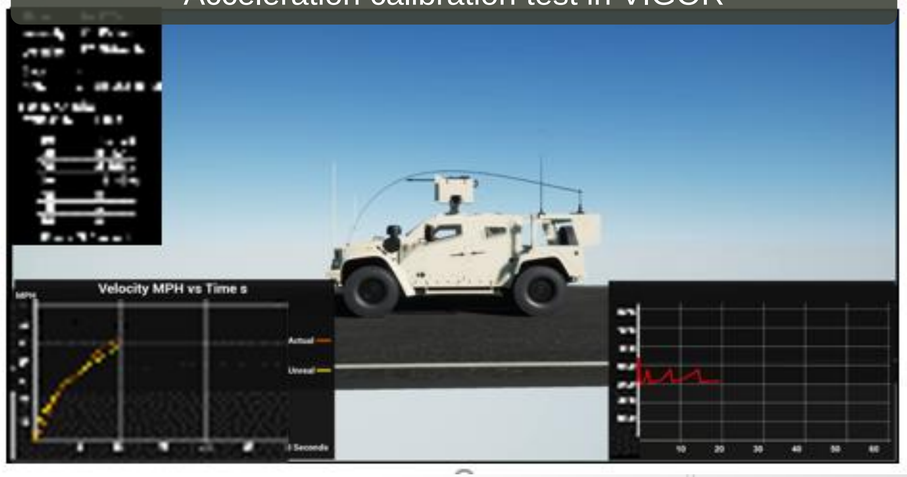
Vehicle	Validation Status
HMMWV	Partially validated
MTVR	Partially validated
MRZR	Validated
PLS	Validated
EMAV	Partially validated
FMTV	Partially validated
JLTV	Validated

Accurate and real-time vehicle mod[illegible] autonomy to control duri[illegible]

Steering calibration test in VIGOR



Acceleration calibration test in VIGOR



VANE Simulation Component: ESE Sensor Models

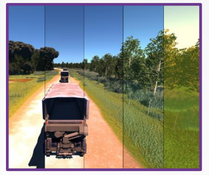
VANE::Environment-Sensor Engine (ESE)

- Uses high-fidelity sensor models to generate realistic synthetic sensor data
  - *Replicates common sensor error found in real world*
- Includes environmental effects that can degrade sensor perception
  - *Weather, lighting, polarization, etc.*
- Can vary fidelity/complexity to balance accuracy and speed of simulations
- Can generate labeled training data for algorithm development

Existing Sensor Modalities Supported by VANE::ESE	Physical Errors Replicated in VANE::ESE
Lidar	Mixed pixel
GNSS	Multi-path, occlusion
Cameras (RGB, Hyperspectral, Stereo)	Motion blur, lens distortion
IMU	Position drift

Current Key Environmental Factors in ESE

Lighting



- Time-of-day
- Shadows
- Atmosphere haze

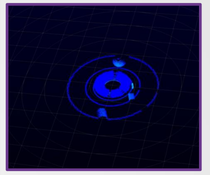
Rain

- Variable rainfall rate
- Wind effects

Dust

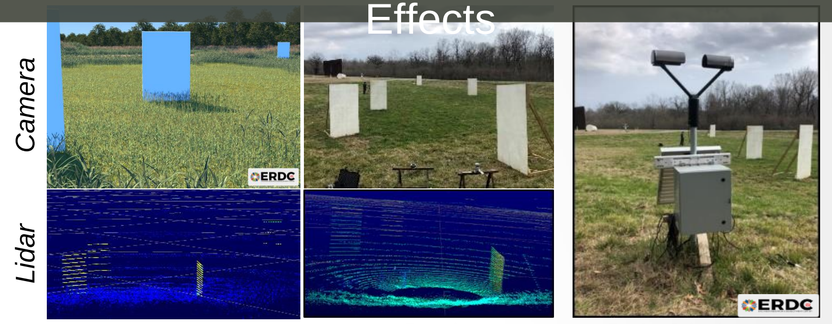
- Vehicle-generated dust
- Wind effects

Fog



- Variable fog density
- Beam/fog options for fidelity vs. performance

Field V&V Experiments for Sensors and Rain Effects



Simulated *Real* *Rain Disdrometer*

High-fidelity sensor simulations provide realistic data for a wide variety of environmental conditions at a fraction of the time and cost of physical experiments

VANE Virtual Environment V&V

Data Collection: In-Situ

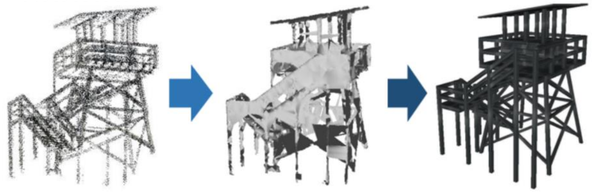
- Base-station referenced LIDAR (<cm accurate)
- Normalized RGB images
- Vegetation distribution
- Soil data

Data Collection: Remote-Sensed

- Digital Elevation model (DEM)
  - Merge with hi-res LIDAR data
- Satellite Image
  - Vegetation masks
  - Terrain texture masks

Generate Environment Files

- Model/texture building meshes
- Generate vegetation locations
- Create twinned VIGOR/ESE scenes



Scene V&V

- Compare vegetation placement with satellite
- Compare simulated orthogonal image with satellite
- Drive virtual vehicle along roads and compare GPS traces with ground truth
- Comparing cross-sections of key-terrain features with ground truth

VANE virtual environments (or "scenes") provide the canvas for sensor and vehicle simulations and must be sufficiently realistic if the simulation is to accurately demonstrate an autonomous system's behavior

Example Environments: Camp Grayling 1420

- Camp Grayling (CGMI) 1420 is the robotic test area at Camp Grayling, MI
- Used by U.S. Army autonomous ground vehicle research programs
- 16 sq. km. of hills, sandy ground, with a mix of fields, sparce trees and thick forested areas
- Geospecific – based on actual location with *in-situ* data collection and no overt modifications

Example Environments: EUCOM

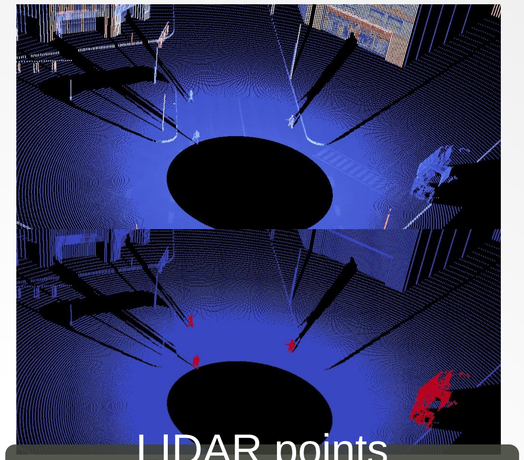
- Reconstruction of a typical European town and surrounding countryside
- Rolling hills, farmland, sparse trees, a lake, numerous roads, and the town itself
- Built using COTS (Commercial Off-the-Shelf) and GOTS (Government Off-the-Shelf) data and pre-existing assets
- Started as a Geospecific-Remote Sensed scene (no *in-situ* data), but was modified to become Geotypical to expand its utility for unmanned vehicles by the addition of a dense forest south of the town

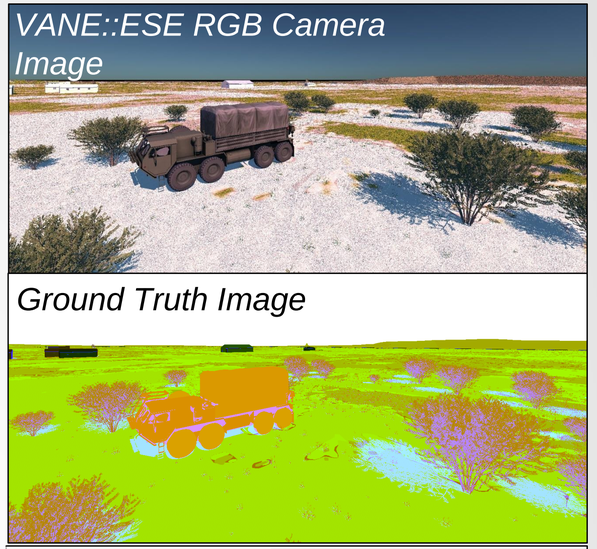
Example Environments: Challenge Arenas

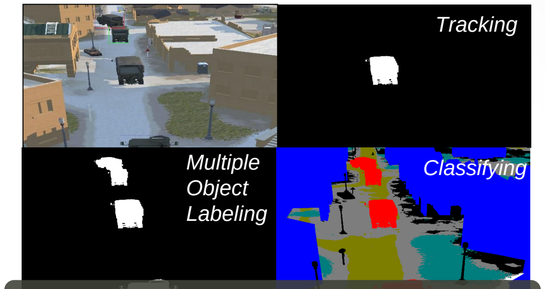
- Consists of a set of small-scale parameterized scenes
- Serves to provide a basis for detailed, quantitative analysis of unmanned ground vehicle (UGV) performance between different autonomy stacks or the improvements between incremental software versions
- Systemically vary terrain, road, and vegetation characteristics

Simulation Modes: Synthetic Training Data Generation

- VANE::ESE supports generating RGB camera and LIDAR training data
- Can rapidly generate ~10,000 synthetic training images (automated in hours/days)
- Can vary all ESE environmental parameters (e.g. lighting, meteorology)
- Can include multiple objects (different instances or types)
- Leverage scene generation scripts for complex environments (results in high entropy datasets)
- Has produced ~100,000's RGB Images for use in algorithms
  - Localization based on terrain features
  - Object detection and classification







Versatile labeling

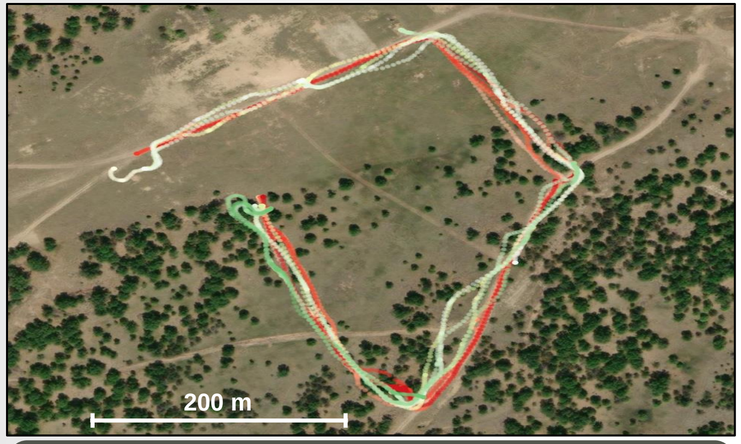
Fully labeled ESE image

VANE accelerates machine learning algorithm development by providing synthetic data with sufficient entropy and metadata to fulfil training needs for robust object detection and classification

VANE Virtual Engineering Evaluation Test (V-EET) 22.2

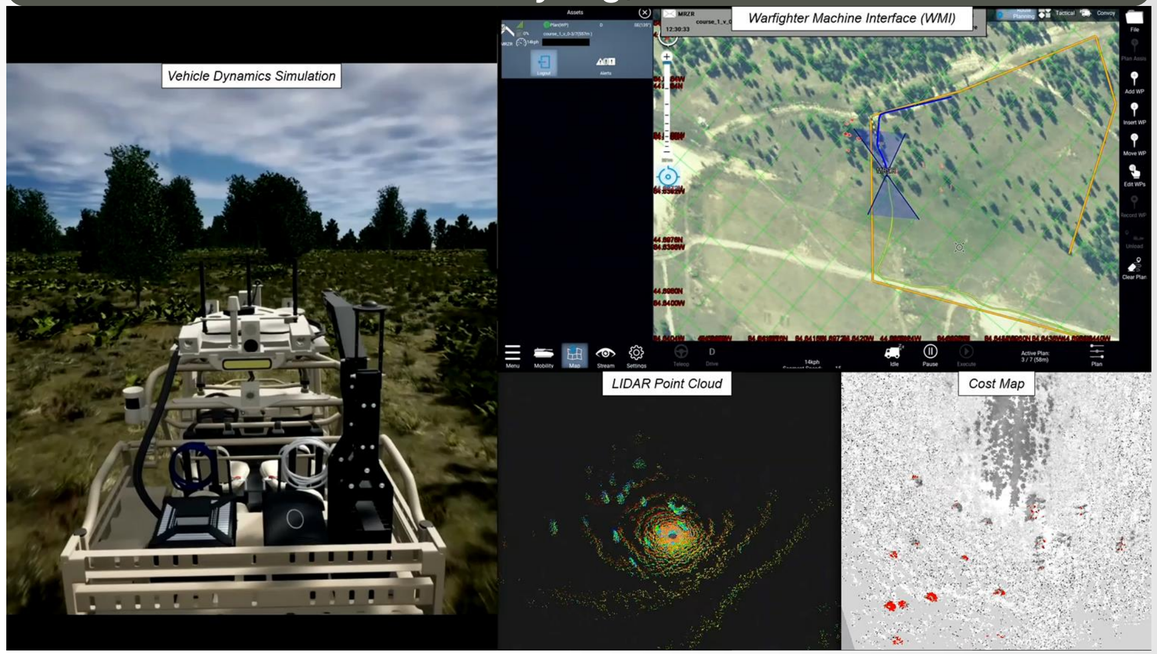
The Test

- In support of the GVSC Combat Vehicle Robotics (CoVeR) program
- Extension of the Engineering Evaluation Test (EET); physical testing conducted at Camp Grayling, MI in the Spring of 2022
- Simulations with the Robot Technology Kernel (RTK) controlling a Polaris MRZR
- VANE::ESE simulated the lidar sensors, and VANE:VIGOR simulated the ground and vehicle models



UGV path comparison of multiple real and virtual experiments

V-EET 22.2 simulations in virtual environment of Camp Grayling, MI



The Results

- Proved to be less expensive and conducted more tests than the EET
- Uncovered a previously unknown software error that had gone unidentified during physical testing
- Performance between physical and virtual testing was similar
- Verified VANE is close enough to physical results to be used as a predictive model

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