MODELING, SIMULATION,
PROTOTYPING & VALIDATION

AI/ML Digital Twins of Hardware-in-the-Loop Systems

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Bottom Line Up-Front

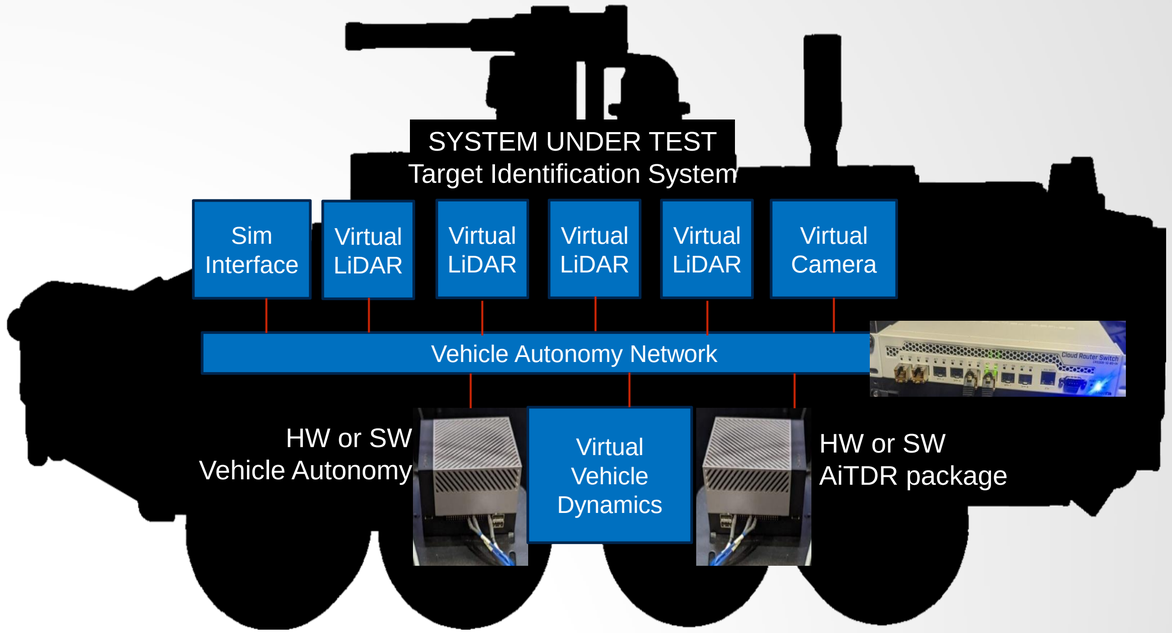
- Digital Engineering facilitates acquisition and lifecycle management by representing engineered systems within a modeling framework in which designs, requirements, functionalities and logical flows can be tested, evaluated and executed in model space.
- Digital Twins facilitate Digital Engineering by providing highly representative models of systems and subsystems within the Digital Engineering framework.
- **GAP:** Creating Digital Twins of sufficient fidelity can be time-consuming and costly.
- We will discuss three examples where AI/ML techniques have deflated cost and schedule in developing Digital Twins.
- These examples live in a “sweet spot” where we find problems that are complex enough to warrant treatment with AI/ML, but not so complex as to require HPC-level investment.
- Therefore, these are not novel AI approaches, but novel application of traditional AI/ML approaches that facilitate digital engineering at modest cost.

Using AI/ML to Black Box

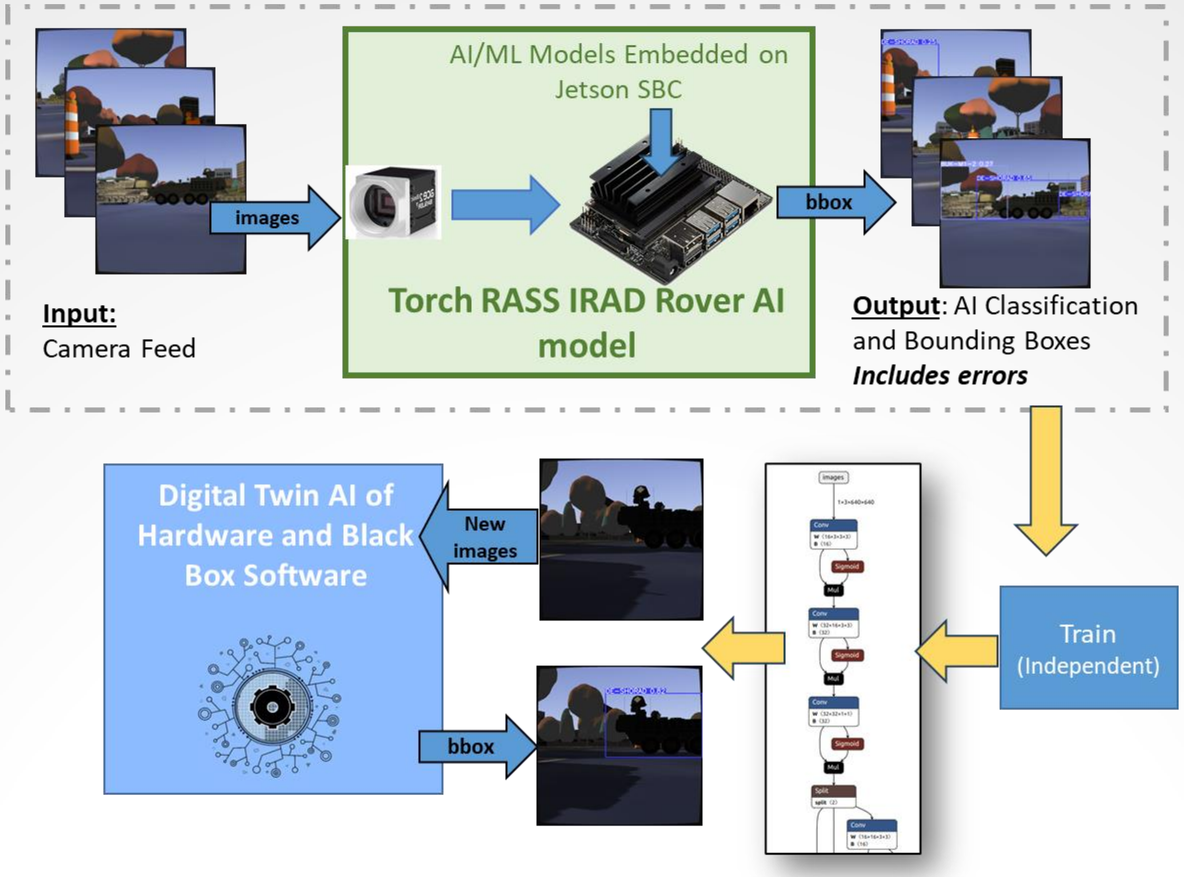
- Use existing AI/ML to rapidly develop and deploy digital twins of HWIL and software systems.
- Leverage off-the-shelf solutions.
- Reduce the Non-Recurring Engineering in Modeling and Simulation.
- Support validation of existing software digital twins.
- Additional Benefits:
  - Create portability of obsolete or proprietary components.
  - Avoid exposing critical technologies.

Case Studies

- Created black boxes of components using various AI/ML.
- Systems in a complexity “sweet spot.”
- Complex enough to justify an AI/ML approach, but not impractical.
- Provide samples across a broad array of system types:
  - Unmanned Ground System Components
  - 6-DOF Simulation Responses
  - Ground Vehicle Line-Replaceable Units



UGS Camera Classifier



- Trained Black Box with no direct collaboration with SMEs in matter of weeks.
- Use only inputs/outputs of subsystem.

- Acceptable Digital Twin performance.
- Low-fidelity simulation environment led to False Positives.
- Captured errors of modeled system.

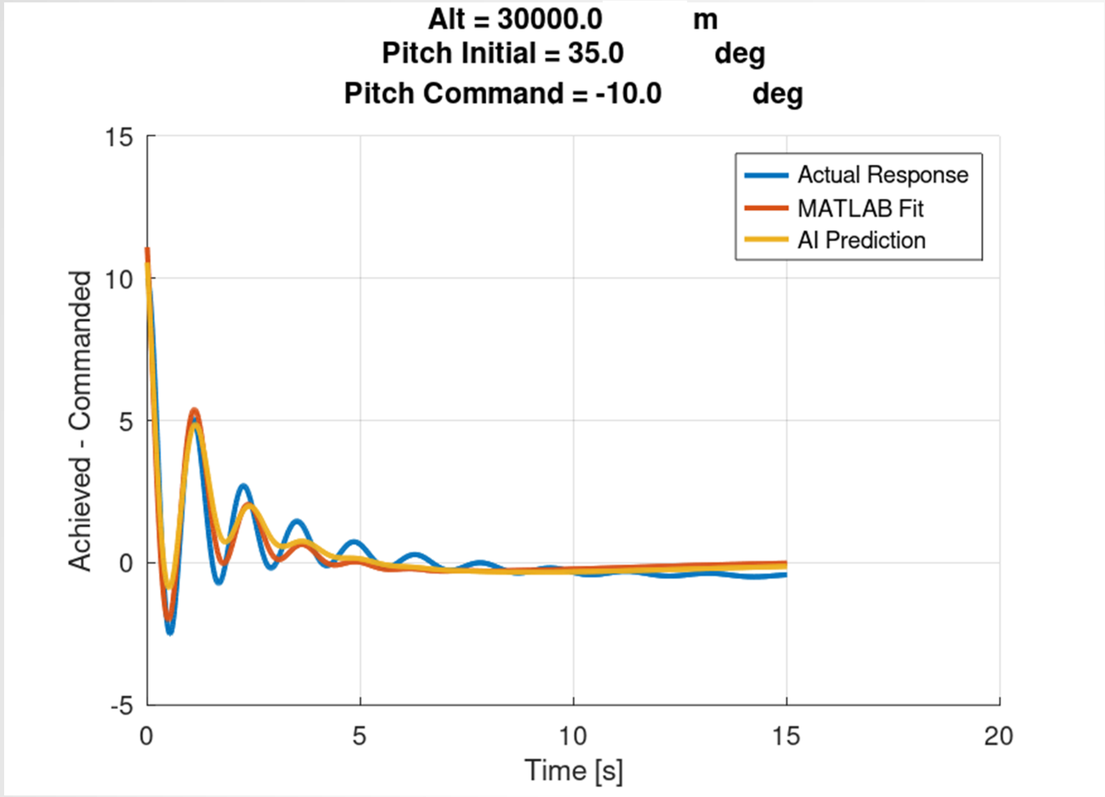
UGS Camera Classifier

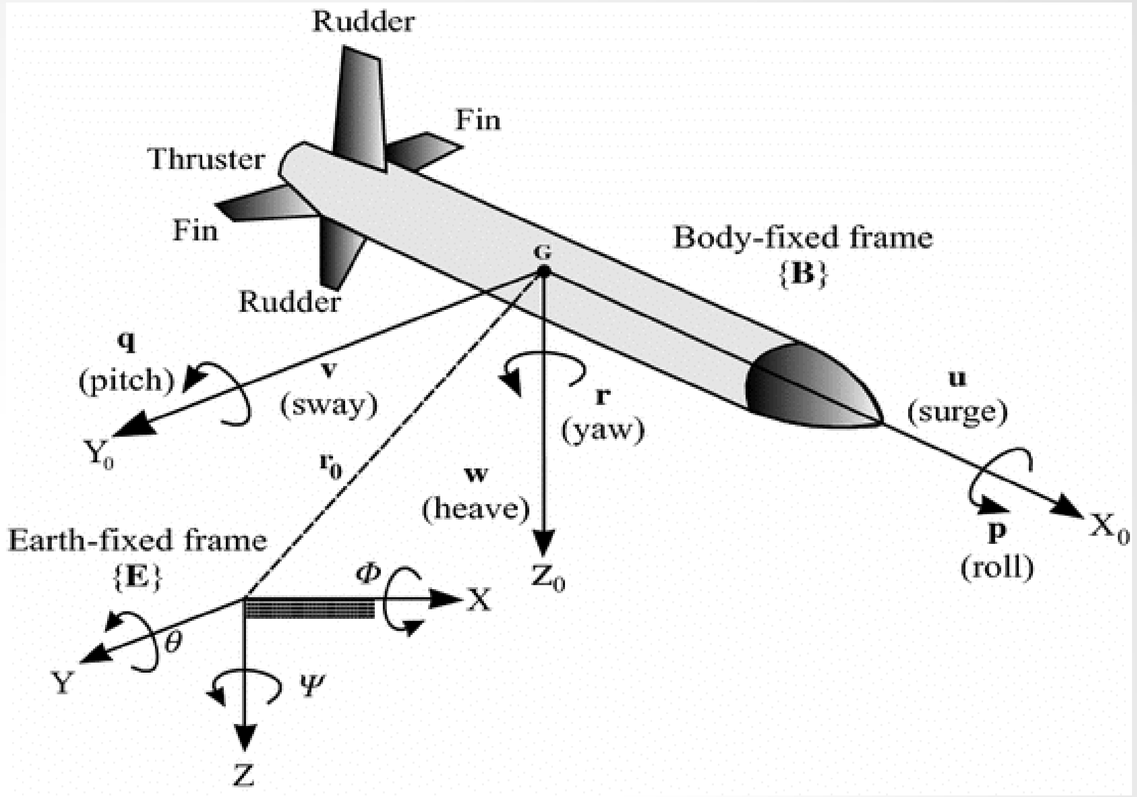
Truth – Their AI prediction during runtime

Our prediction during validation

Classifications Match and Bounding Box is High Confidence (> 50%)

Missile Autopilot Response





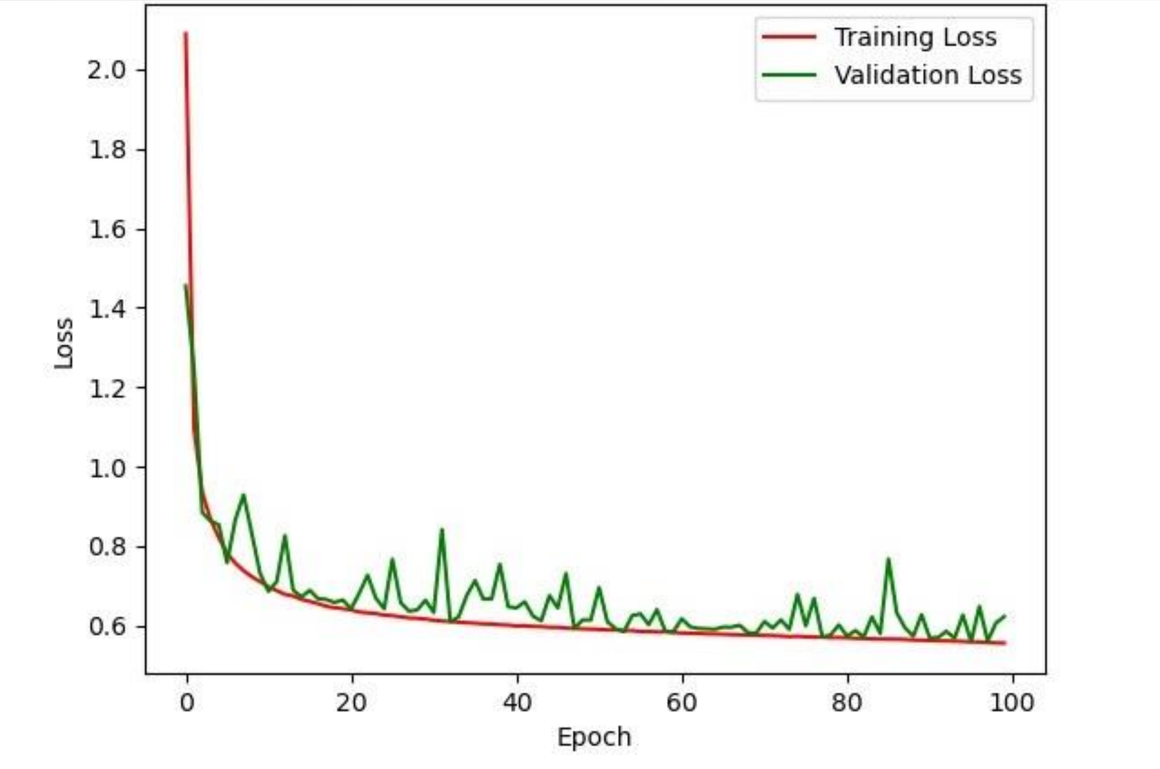
- NSim 6-DOF digital missile system.
- Autopilot pitch response to a step guidance command.
- Completed modeling in <4 weeks.

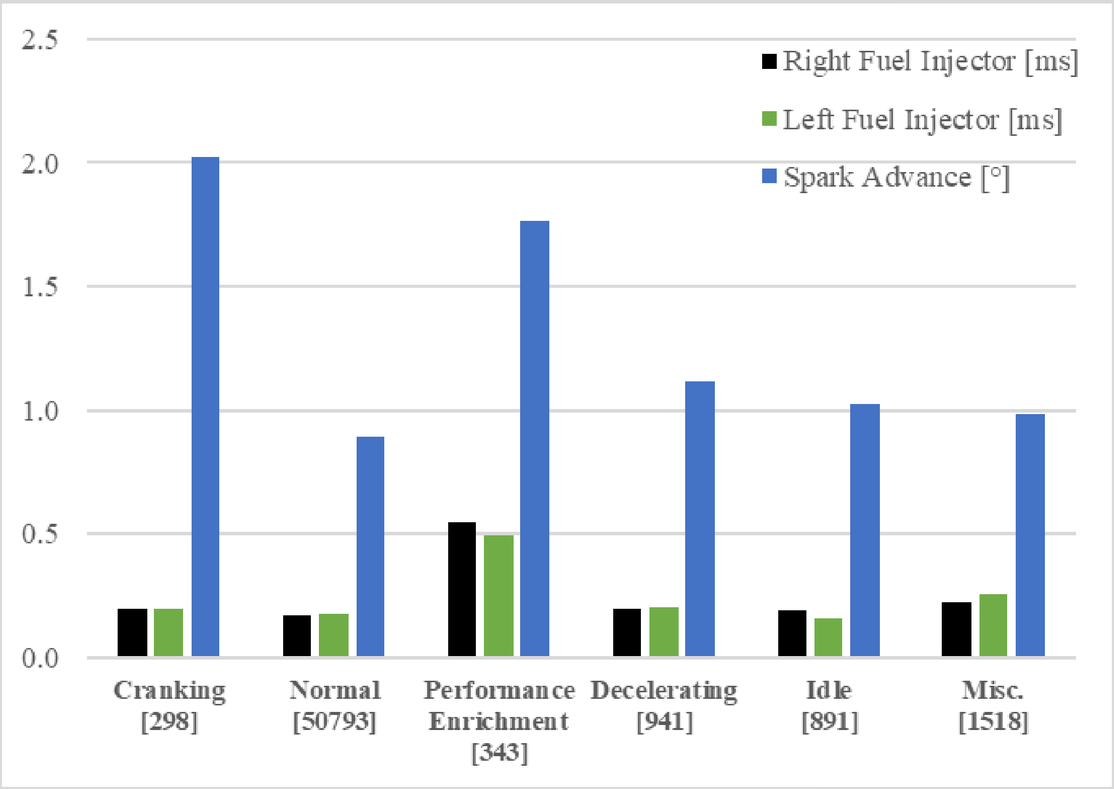
- Can now execute 15x Digital Twin runs in 6-DOF execution time.
- Gain in execution speed enables advanced fire control.

Ground System LRU

- Ground System Line-Replaceable Units (LRUs) explored using a 1996 Caprice as ground system.
- The ODB-1 Powertrain Control Module was modeled as a black box.
- Used the same Feed Forward Neural Network architecture as the Autopilot Response model.

Ground System LRU Model

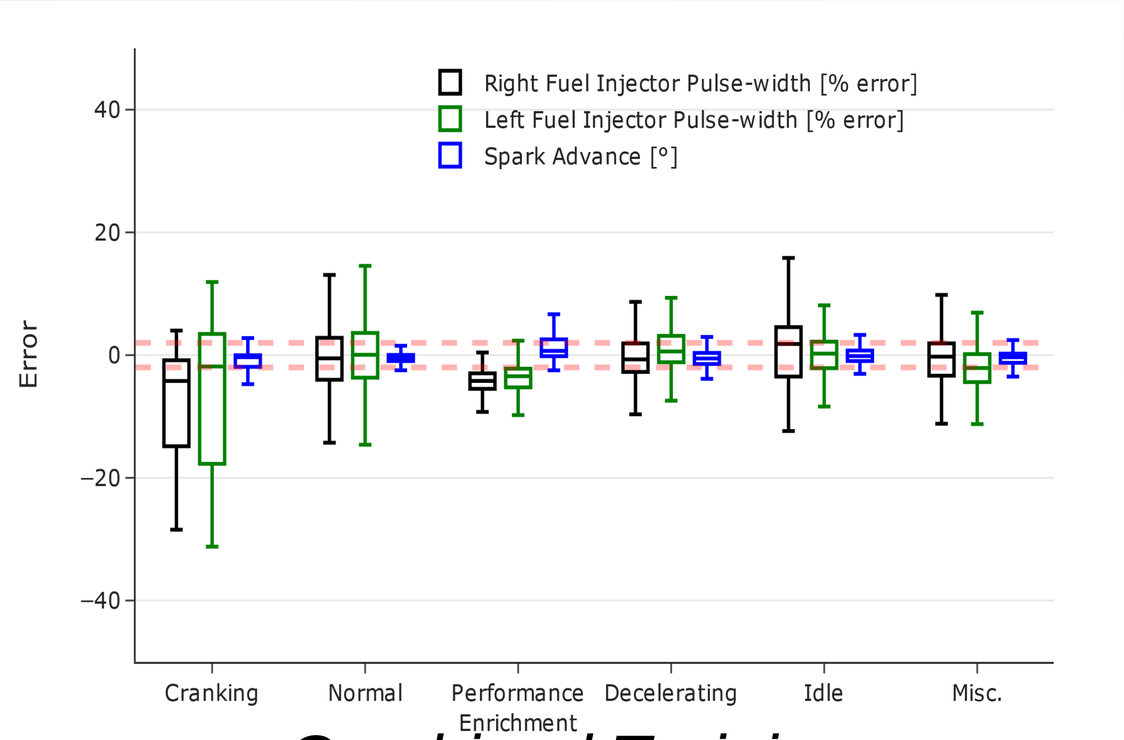




- Deep Feed-forward Neural Network with 0.96 Coefficient of Determination (R^2).

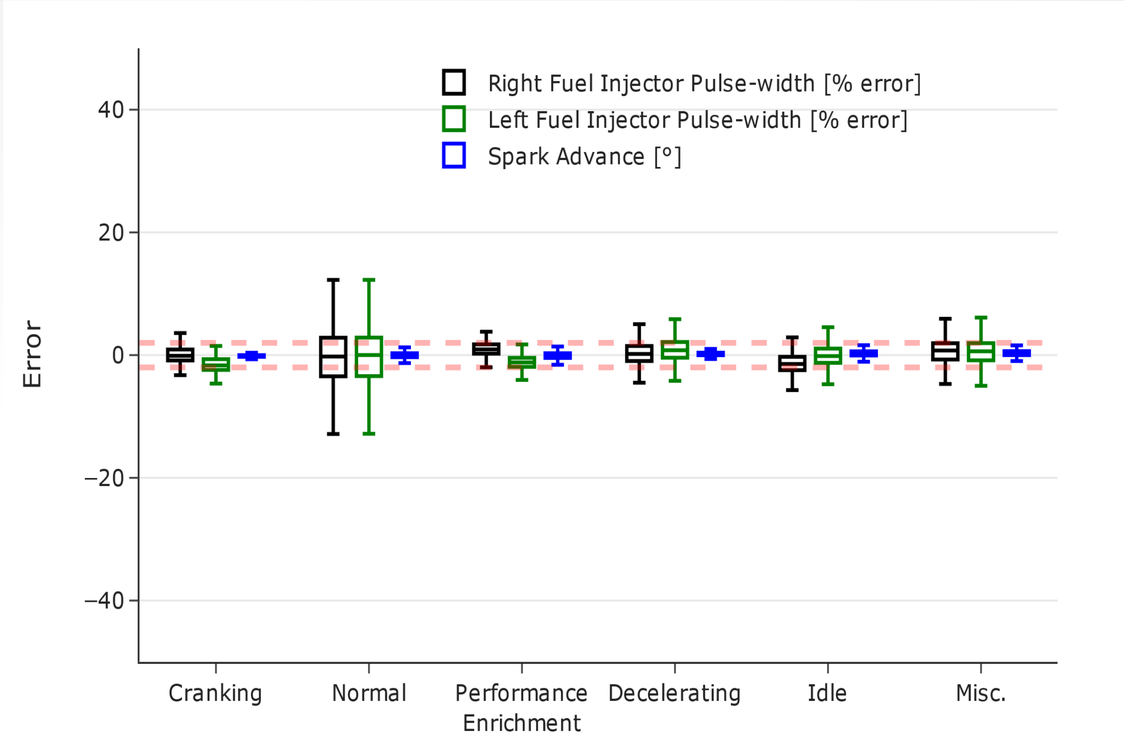
- PCM generalized model had mean errors within SME tolerances (±2°, ±2ms).
- Outliers presented challenge during edge cases.

Integrating SME Guidance



Combined Training

- SME recommended segmenting dataset by LRU operating mode.
- Dramatic reductions in errors across range of conditions.



Segmented Training

- Hardware subsystem rapidly modeled as Digital Twin in 90 days.
- SME guidance yielded significant improvements to the initial design.

AI/ML Digital Twin Lifecycle Applicability

Concept Assessment

- Explore large parameter space during design processes.
- Characterize performance and identify potential failure modes.
- Avoid costly investments with proof-of-principal digital twins.

Integrated System Performance

- Use AI/ML to close gap in schedule developing systems-of-systems.
- Exhibit complex behavior of integrated subsystems.
- Facilitates modularity of subsystems.

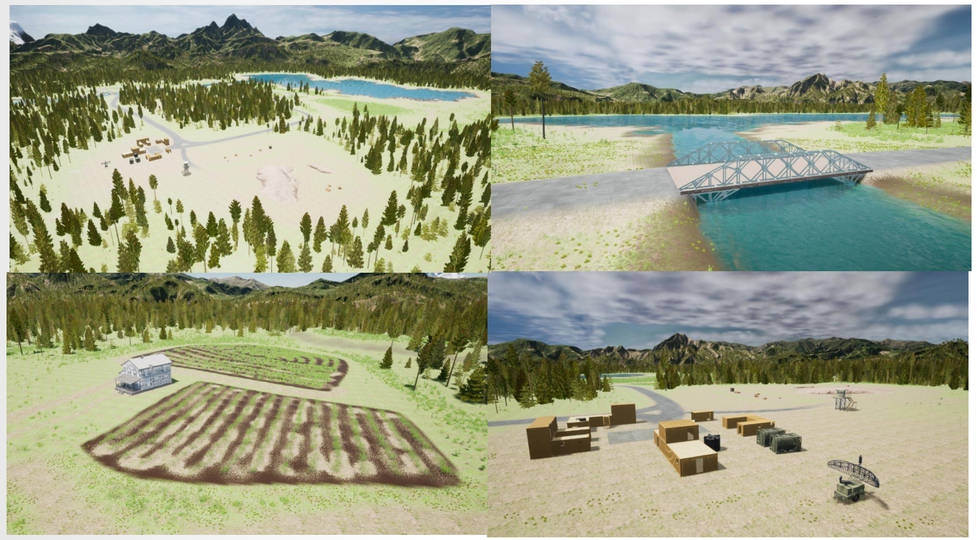
Subsystem Performance

- Digital twin development cost and schedule reduced with AI/ML.
- Generally outstanding performance.
- Rapidly execute across full range of conditions.
- Guide real world testing.

AI/ML Digital Twin Lifecycle Applicability

Test and Evaluation

- Integrate black boxes into full-scale, real-world HWIL of new or updated systems.
- Present realistic stimuli and interactions to System Under Test.



Obsolescence Management

- Mimic LRUs at high fidelity on general purpose hardware.
- Alternative to reverse engineering.
- Reduce impact of obsolescence risk.

Conclusions

- Explore large swaths of configuration space with low/med/high fidelity digital twins.
- Shrink timeline and budget of extensive modeling process involving SMEs.
- Provide sufficient computational performance to execute with HWIL or live systems.
- AI/ML models can accelerate testing, analysis, CONOPS development and lifecycle management at the US Army GVSC.

Q&A

Visit us at our booth (217) for further conversation and demonstrations.

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