Project Plan for Scenario-Based Digital Twin and Control Development

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Project Overview

This document presents a compressed, bi-weekly execution plan for the development of a scenario-based digital twin, embedded torque vectoring control, and virtual drivetrain re-architecture of an electric three-wheeler. All milestones are validated using realistic driving scenarios generated in a RoadRunner virtual environment.

1 Milestone 1: Scenario-Synchronized Digital Twin Development

Duration

Weeks 1–4 (End of February)

Objective

Finetune the current model by integrating more sensors (IMU, steering sensor) into a **high-fidelity, digital twin** of the three-wheeler by integrating controller, motor, brake, and CAD-based Simscape Multibody dynamics, and validate its behavior across **realistic driving scenarios** using a **RoadRunner virtual environment**.

Weeks 1–2: Sensor integration and characterization of power-train (Motor + Controller)

- Will integrate real sensors (IMU sensor and steering sensor) to measure the dynamics of the vehicle.
- Integration of virtual sensors (IMU, steering sensor)
- We **do not have the motor parameters** to model it perfectly, so **characterization of the motor and controller** for better model fidelity.

Weeks 3–4: Scenario Validation and Calibration

- Synchronization and replay of real vehicle inputs (where available)
- Validation of vehicle behavior across RoadRunner scenarios.
- Demonstration of short-horizon prediction and energy estimation

Milestone 1 Exit Criteria

A scenario-validated, physics-synchronized digital twin suitable for control development and further system-level analysis.

2 Milestone 2: Torque Vectoring Development and SPC58 Deployment

Duration

Weeks 5–10 (Mid-April)

Objective

Design, validate, and deploy a **torque vectoring controller** on the **SPC58 automotive micro-controller** using a staged **Controller-in-the-Loop (CIL) to Hardware-in-the-Loop (HIL)** workflow, with validation performed using **RoadRunner-based driving scenarios**.

Weeks 5–6: Development of LTI state model for 3-wheeler and implementation of different torque vectoring strategy

- Development of a physics equation-based linear time-invariant (LTI) state model of three-wheeler to develop the controller for torque vectoring in MATLAB environment, and then comparing the results of all the torque vectoring strategies and picking the best strategy depending upon vehicle stability and ride comfort.
- Following the recent similar work in 3-wheeler stability and taking it forward for implementation: `https://link.springer.com/chapter/10.1007/978-981-96-7707-8_42#citeas`

Weeks 7–8: Controller-in-the-Loop Validation

- Integration of torque vectoring controller with the digital twin
- Validation across RoadRunner scenarios (curves, split-μ, transient maneuvers)
- Controller gain tuning and safety limit enforcement
- Verification of stability improvement and robustness in digital twin environment.

Weeks 9–10: Embedded Deployment and HIL Testing

- Refactoring of controller for fixed-step, real-time execution
- Code generation and deployment on the SPC58 microcontroller
- Hardware-in-the-Loop testing using scenario replay
- Limited, controlled on-vehicle validation (where feasible)

Milestone 2 Exit Criteria

A scenario-validated torque vectoring controller successfully deployed and operating in real time on the SPC58 platform.

3 Milestone 3: Virtual Re-Architecture and Stability Validation Using Scenario-Based Digital Twin

Duration

(***Will be working on it in parallel***)

Objective

Virtually re-architect the three-wheeler from a **dual rear hub-motor drive** configuration to a **single front-wheel motor drive**, and validate its **stability and dynamic behavior** across multiple RoadRunner scenarios, demonstrating a **virtual-first vehicle development methodology** that dramatically reduces physical testing cost and time.

Weeks 11–12: Drivetrain Re-Architecture

- Building the MATLAB multibody model from scratch using CAD design from SolidWorks.
- Introduction of front-wheel motor drive configuration.

Weeks 13–14: Scenario-Based Stability Evaluation

- Execution of aggressive RoadRunner scenarios including cornering, braking-in-turn, uneven roads, and emergency maneuvers
- Analysis of yaw response, wheel slip, and stability margins
- Comparative evaluation of rear-drive and front-drive configurations
- Definition of go/no-go recommendation for physical prototyping

Milestone 3 Exit Criteria

Demonstrated capability to evaluate and iterate vehicle architecture by validating vehicle stability and dynamic behavior virtually, the approach enables rapid design iteration while significantly reducing physical testing cost, risk, and development time.