2025-11-01

E003: Plant Models and Dynamics

DIP-SMC-PSO Educational Series

January 25, 2026

Overview

This episode covers plant models and dynamics from the DIP-SMC-PSO project.

Part: Part1 Foundations

Duration: 15-20 minutes

Source: Comprehensive Presentation Materials

section0 Three Fidelity Levels

- **Simplified Dynamics** – Linearized, fast prototyping
  - ‘src/plant/models/simplified_dynamics.py‘ - 98 - Ideal for initial controller design
  - **Full Nonlinear Model** – High-fidelity with coupling effects
  - ‘src/plant/models/full_nonlinear_dynamics.py‘ - Includes centripetal, Coriolis forces - Used for final validation
  - **Low-Rank Approximation** – Computationally efficient reduced-order
  - ‘src/plant/models/lowrank_dynamics.py‘ - Truncated state representation - Suitable for real-time embedded systems

Accuracy vs Computational Cost – Choose based on application requirements

section0 Physical System Parameters

Default Configuration (‘config.yaml):‘

Parameter	**Value**	**Units**
Cart mass (m_0)	1.0	kg
Pole 1 mass (m_1)	0.1	kg
Pole 2 mass (m_2)	0.1	kg
Pole 1 length (ℓ_1)	0.5	m
Pole 2 length (ℓ_2)	0.5	m
Gravity (g)	9.81	m/s^2
Control Constraints:		
Max force (u_{max})	20.0	N
Min force (u_{min})	-20.0	N

Tested parameter variations:
*Low:** ±10 All controllers remain stable under ±10

section0 State Space Representation

6-Dimensional State Vector:

$$equation = x\dot{x}\theta_1\dot{\theta}_1\theta_2\dot{\theta}_2^T \quad (0)$$

where:
- x – Cart position - $\dot{x}$ – Cart velocity - θ_1 – Pole 1 angle (from vertical) - $\dot{\theta}_1$ – Pole 1 angular velocity - θ_2 – Pole 2 angle (from vertical) - $\dot{\theta}_2$ – Pole 2 angular velocity

Control Input:

$$equation = u \quad (horizontal force on cart) \quad (0)$$

Initial Condition (typical):

$$equation_0 = [0, 0, 0.1, 0, -0.05, 0]^T \quad (small angular perturbations) \quad (0)$$

section0 Lagrangian Formulation

Equations of Motion:

$$equation(\mathbf{q})\ddot{\mathbf{q}} + (\mathbf{q}, \dot{\mathbf{q}})\dot{\mathbf{q}} + (\mathbf{q}) = \quad (0)$$

where:
- $\mathbf{q} = [x, \theta_1, \theta_2]^T$ – Generalized coordinates - – Mass/inertia matrix (3×3, positive definite) - – Coriolis/centripetal matrix (3×3) - – Gravity vector (3×1) - – Input mapping (3×1)

Key Properties:

- **Nonlinearity:** , , depend on $\mathbf{q}$ - **Underactuated:** 3 DOF, 1 actuator - **Coupling:** Motion of one pole affects the other

section0 Mass Matrix Structure

General Form:

$$equation = M_{00}M_{01}M_{02}M_{10}M_{11}M_{12}M_{20}M_{21}M_{22} \qquad (0)$$

Explicit Elements (simplified): $\mathrm{M}_{00} = m_0 + m_1 + m_2$
$M_{01} = (m_1 + m_2)\ell_1 \cos\theta_1$
$M_{02} = m_2\ell_2 \cos\theta_2$
$M_{11} = (m_1 + m_2)\ell_1^2$
$M_{12} = m_2\ell_1\ell_2 \cos(\theta_1 - \theta_2)$
$M_{22} = m_2\ell_2^2$
can become ill-conditioned at certain configurations
Robust inversion required: ‘numpy.linalg.solve(M, rhs)‘

section0 Plant Architecture: Code Organization

Module Structure:

- ‘src/plant/core/‘ – Core interfaces, base classes
- ‘physics_matrices.py‘ – , , computation - ‘state_validation.py‘ – Bounds checking, NaN detection
- ‘src/plant/models/‘ – 8 dynamics files
- ‘simplified_dynamics.py‘ – Linearized (98 - ‘full_nonlinear_dynamics.py‘ – High-fidelity - ‘lowrank_dynamics.py‘ – Reduced-order - 5 other variants (experimental)
- ‘src/plant/configurations/‘ – Predefined plant setups
- ‘default_config.yaml‘ – Standard parameters - ‘heavy_cart.yaml‘ – Increased m_0 - ‘long_poles.yaml‘ – Increased ℓ_1, ℓ_2

Resources

- **Repository:** `https://github.com/theSadeQ/dip-smc-pso.git`
- **Documentation:** See `docs/` directory
- **Getting Started:** `docs/guides/getting-started.md`

Educational podcast episode generated from comprehensive presentation materials