

2025-11-01

E004: PSO Optimization Fundamentals

DIP-SMC-PSO Educational Series

January 25, 2026

Overview

This episode covers pso optimization fundamentals from the DIP-SMC-PSO project.

Part: Part1 Foundations

Duration: 15-20 minutes

Source: Comprehensive Presentation Materials

section0 Particle Swarm Optimization: Overview

****Inspiration:**** Social behavior of bird flocking, fish schooling

****Algorithm:**** Population-based stochastic optimization

- ****Particles:**** Candidate solutions in search space - ****Velocity:**** Direction and speed of movement - ****Personal best:**** Best solution found by each particle - ****Global best:**** Best solution found by entire swarm

****Update Equations:**** $v_i^{(t+1)} = wv_i^{(t)} + c_1r_1(p_i - x_i^{(t)}) + c_2r_2(g - x_i^{(t)})$
 $x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)}$

where:

- w – Inertia weight (0.729) - c_1, c_2 – Cognitive/social coefficients (1.494 each) - r_1, r_2 – Random numbers $\in [0, 1]$ - p_i – Personal best, g – Global best

section0 PSO for Controller Gain Tuning

****Objective:**** Find optimal controller gains to minimize cost function

****Search Space:**** Controller gains (6-dimensional for classical SMC)

$$\text{equation}\mathbf{x} = [k_1, k_2, \lambda_1, \lambda_2, K, \epsilon] \quad (0)$$

****Cost Function (Multi-Objective):****

$$\text{equation}J = w_1 \cdot ISE + w_2 \cdot t_{\text{settle}} + w_3 \cdot \int u^2 dt + w_4 \cdot \text{chattering} \quad (0)$$

where:

- $ISE = \int (\theta_1^2 + \theta_2^2) dt$ – Integral squared error - t_{settle} – Settling time - $\int u^2 dt$ – Control effort - chattering – High-frequency energy metric

Complete – Convergence curves, particle trajectories, fitness landscapes

section0 PSO Algorithm Parameters

****Default Configuration:****

****Parameter**** ****Value****

Number of particles 30

Generations 50-100

Inertia weight (w) 0.729

Cognitive coefficient (c_1) 1.494

Social coefficient (c_2) 1.494

Convergence Criteria:

Fitness tolerance 10^{-6}

Max stagnation generations 10

Complete – Tested across 100 seeds, validated convergence reliability

Integrated into LT-7 research paper

section0 PSO Convergence Analysis

****Typical Convergence Curve:****

[Visual diagram - see PDF]

****Characteristics:****

- ****Rapid initial decrease:**** Exploration phase (generations 0-30) - ****Gradual refinement:**** Exploitation phase (generations 30-100) - ****Convergence:**** Fitness plateau indicates optimal solution found

section0 Optimization Results: Controller Comparison

****Optimized Gains (MT-5 Benchmark):****

Controller	**Settling Time (s)**	**ISE**	**Energy (J)**
Classical SMC	2.5	0.45	12.3
STA-SMC	2.1	0.38	10.8
Adaptive SMC	2.3	0.41	11.5
Hybrid Adaptive STA	**2.0**	**0.35**	**10.2**

- ****Best overall:**** Hybrid Adaptive STA-SMC - ****Lowest chattering:**** STA-SMC - ****Fastest convergence:**** PSO typically converges in 60-80 generations - ****Repeatability:**** 95

section0 Alternative Optimization Algorithms

****Implemented but not primary:****

- ****CMA-ES**** (Covariance Matrix Adaptation Evolution Strategy)
- Better for high-dimensional problems - 'src/optimization/algorithms/cma_es.py'
- ****Differential Evolution (DE)****
- Simple, robust global optimizer - 'src/optimization/algorithms/differential_evolution.py'
- ****Genetic Algorithm (GA)****
- Classic evolutionary approach - 'src/optimization/algorithms/genetic_algorithm.py'

PSO is primary method (best performance for this application)

Other algorithms available for research/comparison

Resources

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