Training Course on Digital Control System Design

Professional Development Training Course Outline

Category	Engineering	**Duration**	10 Days
Base Fee	$3,000 USD	**Delivery Mode**	Online / On-site Hybrid

Course Introduction

Introduction

Step into the essential realm of modern control engineering with our intensive training course on Digital Control System Design. In an era dominated by digital transformation and embedded systems, understanding how to design, analyze, and implement control systems using microcontrollers, DSPs, and FPGAs is paramount. Training Course on Digital Control System Design provides a thorough grounding in the discrete-time domain, equipping participants with the critical skills to convert continuous-time concepts into their digital counterparts, addressing sampling, quantization, and digital filter design. You will gain expertise in creating precise, reliable, and high-performance control solutions that underpin virtually all modern industrial, automotive, and consumer electronics applications.

This comprehensive course is tailored for engineers, developers, and researchers seeking to master the intricacies of digital control algorithm development for real-time applications. We will delve into trending topics such as z-transform analysis, digital PID controller design, state-space digital control, finite word length effects, and hardware-in-the-loop (HIL) testing. Participants will engage in practical exercises and case studies, gaining hands-on experience with industry-standard software tools to design and validate robust digital control systems. Join us to build the foundational knowledge and practical skills required for innovation in smart systems, robotics, and advanced automation.

Programme Curriculum

Training Course on Digital Control System Design

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Course Objectives

1. Understand the fundamental differences and relationships between continuous-time and discrete-time control systems.
2. Master the z-transform and its application in analyzing and designing digital control systems.
3. Design and implement digital PID controllers with advanced tuning methods for discrete systems.
4. Analyze the effects of sampling rate, quantization, and finite word length on digital control system performance.
5. Develop state-space models for discrete-time systems and design state-feedback controllers.
6. Implement digital filters (FIR, IIR) for noise reduction and signal conditioning in control loops.
7. Utilize various digital controller discretization methods (e.g., Tustin, zero-order hold) and their implications.
8. Evaluate the stability and robustness of digital control systems using discrete-time analysis tools.
9. Apply digital control principles to real-time embedded systems using microcontrollers.
10. Design control algorithms for distributed control systems and networked environments.
11. Perform hardware-in-the-loop (HIL) testing and validation for digital control systems.
12. Troubleshoot and debug common issues in digital control system implementation.
13. Contribute to the development of smart systems, robotics, and automation leveraging digital control techniques.

Organizational Benefits

1. Enhanced System Performance: More precise and responsive control in digital environments.
2. Reduced Development Time: Efficient design and implementation of digital controllers.
3. Improved System Reliability: Robust digital designs with predictable behavior.
4. Cost-Effective Solutions: Leveraging digital hardware for complex control tasks.
5. Greater Flexibility: Easier modification and adaptation of digital control algorithms.
6. Competitive Advantage: Expertise in cutting-edge digital control technology.
7. Optimized Resource Utilization: Efficient use of computing power in embedded systems.

8. Skilled Workforce: Engineers proficient in modern digital control design and implementation.
9. Support for Industry 4.0 Initiatives: Foundation for interconnected and autonomous systems.
10. Faster Troubleshooting: Systematic approaches to diagnosing digital control issues.

Target Participants

- Control Systems Engineers
- Electrical Engineers
- Electronics Engineers
- Embedded Systems Developers
- Automation Engineers
- Robotics Engineers
- Mechatronics Engineers
- Software Engineers interested in real-time control.

Course Outline

Module 1: Introduction to Digital Control Systems

- **Why Digital Control?** Advantages over analog control (flexibility, precision, cost).
- **Continuous vs. Discrete-Time Systems:** Fundamental differences and relationships.
- **The Sampling Process:** Nyquist-Shannon sampling theorem, aliasing.
- **Quantization and Digital Representation:** Analog-to-Digital Converters (ADCs).
- **Overview of Digital Control System Components:** Microcontrollers, sensors, actuators.
- **Case Study:** Converting a simple analog temperature control loop to a digital one.

Module 2: The Z-Transform and Inverse Z-Transform

- **Definition and Properties of the Z-Transform:** Mapping from discrete-time to the z-domain.
- **Common Z-Transform Pairs:** Step, ramp, exponential functions.
- **Inverse Z-Transform Techniques:** Partial fraction expansion, long division.
- **Solving Difference Equations using Z-Transform:** System response to inputs.
- **Case Study:** Analyzing the Z-transform of a simple discrete-time filter.

Module 3: Discrete-Time System Representation and Analysis

- **Pulse Transfer Function (PTF):** Input-output relationship in the z-domain.
- **Poles and Zeros in the Z-Plane:** Stability criteria for discrete systems.
- **Relationship between S-plane and Z-plane:** Mapping stability regions.
- **Frequency Response of Discrete-Time Systems:** Digital Bode plots.
- **Case Study:** Analyzing the stability and frequency response of a given discrete-time system.

Module 4: Digital Controller Discretization Methods

- **Zero-Order Hold (ZOH) Equivalence:** Most common discretization method.
- **First-Order Hold (FOH) Equivalence:** Improved approximation.
- **Tustin (Bilinear Transformation) Method:** Approximating derivatives.
- **Matched Pole-Zero Method:** Preserving pole-zero locations.
- **Case Study:** Discretizing a continuous-time PID controller using ZOH and Tustin methods and comparing results.

Module 5: Digital PID Controller Design and Tuning

- **Discrete PID Algorithm:** Proportional, Integral, Derivative components.
- **Position vs. Velocity Form:** Different implementation approaches.
- **Digital PID Tuning Methods:** Ziegler-Nichols, Cohen-Coon, trial-and-error in discrete domain.
- **Anti-Windup and Bumpless Transfer:** Practical considerations.
- **Case Study:** Designing and tuning a digital PID controller for a motor speed control system.

Module 6: Digital State-Space Control Design

- **Discrete-Time State-Space Representation:** Equations for digital systems.
- **Controllability and Observability for Discrete Systems:** System properties.
- **Discrete State-Feedback Design (Pole Placement):** Placing closed-loop poles.
- **Discrete Kalman Filter (Observer Design):** Estimating unmeasured states.
- **Case Study:** Designing a state-feedback controller for a discrete-time inverted pendulum.

Module 7: Digital Filter Design for Control Systems

- **FIR Filters:** Linear phase, stability, computational cost.
- **IIR Filters:** Efficiency, non-linear phase, stability considerations.
- **Design Methods:** Windowing, Butterworth, Chebyshev, Elliptic filters.
- **Filter Implementation in Real-Time:** Difference equations.
- **Case Study:** Designing a digital low-pass filter to reduce sensor noise in a control loop.

Module 8: Effects of Digital Implementation (Non-Idealities)

- **Sampling Rate Selection:** Trade-offs between performance and computational load.
- **Quantization Errors:** ADC/DAC resolution, overflow, truncation.
- **Finite Word Length Effects:** Integer vs. floating-point arithmetic, scaling.
- **Computational Delay:** Impact on system stability and performance.
- **Case Study:** Analyzing the impact of limited bit resolution on the performance of a digital controller.

Module 9: Real-Time Implementation with Microcontrollers

- **Microcontroller Architecture for Control:** CPUs, memory, peripherals (Timers, PWM, ADC, DAC).
- **Programming for Real-Time Control:** Interrupts, scheduling, task prioritization.
- **Interfacing Sensors and Actuators:** Practical considerations.
- **Data Acquisition and Output Generation:** Reading inputs and driving outputs.
- **Case Study:** Implementing a simple digital PID controller on an Arduino or STM32 microcontroller.

Module 10: Advanced Digital Control Strategies

- **Deadbeat Control:** Achieving desired response in minimal time.
- **Minimum Variance Control:** Optimizing performance for stochastic disturbances.
- **Predictive Digital Control Concepts:** Introducing MPC principles in discrete time.
- **Digital Lead-Lag Compensators:** Shaping frequency response digitally.
- **Case Study:** Designing a deadbeat controller for a discrete-time system.

Module 11: Hardware-in-the-Loop (HIL) Testing

- **Concept of HIL Simulation:** Integrating real hardware with simulated plant.

- **Benefits of HIL Testing:** Early fault detection, reduced development time.
- **HIL System Components:** Real-time processors, I/O interfaces, plant models.
- **Test Case Development and Automation:** Running comprehensive tests.
- **Case Study:** Setting up an HIL test bench for an automotive engine control unit.

Module 12: Digital Control for Robotics and Mechatronics

- **Control of DC and BLDC Motors:** Digital current, velocity, and position loops.
- **Robot Joint Control:** Implementing digital controllers for manipulators.
- **Sensor Integration:** Digital encoders, IMUs for robotic feedback.
- **Real-time Communication Protocols:** CAN, EtherCAT for robotic networks.
- **Case Study:** Designing digital controllers for the joints of a robotic arm.

Module 13: Distributed Digital Control Systems

- **Networked Control Systems (NCS):** Challenges of communication delays and packet loss.
- **Wireless Control Systems:** Reliability and security considerations.
- **Protocols for Distributed Control:** Modbus, EtherNet/IP, OPC UA.
- **Event-Triggered Control:** Reducing communication and computation.
- **Case Study:** Designing a distributed control system for a smart factory floor.

Module 14: Practical Tools and Software for Digital Control Design

- **MATLAB/Simulink:** Control System Toolbox, Simulink Real-Time.
- **Python Libraries:** SciPy, NumPy, Control Systems Library.
- **Code Generation Tools:** From model to embedded code.
- **Debugging and Profiling Tools:**Upcoming Scheduled Sessions

Start Date	End Date	Location	Price
23 Nov 2026	04 Dec 2026	Online	$2,000
23 Nov 2026	04 Dec 2026	Physical	$3,000
23 Nov 2026	04 Dec 2026	Physical	$6,000
23 Nov 2026	04 Dec 2026	Physical	$6,000
23 Nov 2026	04 Dec 2026	Physical	$12,000
23 Nov 2026	04 Dec 2026	Physical	$9,000
23 Nov 2026	04 Dec 2026	Physical	$12,000
23 Nov 2026	04 Dec 2026	Physical	$12,000

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