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Adaptive Multi-tier Neural Architecture for Optimized Environmental Parameter Management in High-Energy Physics Detector Systems

In large-scale particle physics experimentation, maintaining precise control of diverse environmental parameters across complex detector subsystems constitutes a fundamental operational requirement, directly impacting data acquisition integrity, component longevity, and systemic stability. Contemporary slow control infrastructures predominantly employ static threshold parameters, deterministic rule-based decision matrices, and uniform sensor interrogation protocols—methodological constraints that engender suboptimal energy utilization, latent anomaly identification, and restricted deployment scalability. This research introduces a computationally adaptive control framework configured to address the distinctive environmental monitoring and regulation challenges inherent in high-precision detector environments.

The proposed implementation architecture comprises three integrated analytical tiers: (1) spatiotemporal clustering algorithms that establish statistically significant correlations between interdependent environmental sensors based on physical proximity coefficients and temporal behavioral patterns; (2) Graph Neural Network (GNN) predictive modeling that leverages topological relationships to forecast localized and system-wide environmental dynamics under conditions of incomplete or asynchronous sensor data acquisition; and (3) hierarchical reinforcement learning (HRL) optimization that simultaneously develops control policies at discrete component and integrated subsystem levels. Through algorithmic modulation of sensor sampling frequencies and dynamic recalibration of actuator response functions, the system promises to reduce operational redundancy, adapt to environmental perturbations, and implement preemptive intervention strategies for anomaly mitigation across multiple environmental variables within experimental detector systems. The methodological framework and resulting algorithmic implementations are designed for deployment within CERN's experimental infrastructure, with particular emphasis on integration with existing detector control systems while facilitating enhanced operational efficiency and environmental parameter stability.

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