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AI-Driven Power Optimization in IoT Devices: Enhancing Efficiency through Intelligent Electronic Control Systems

Dr. Jyotsna Ogale

Assistant Professor

Department of Electronics

Engineering and Dean of Student's Welfare

with Samrat Ashok Technological Institute, Vidisha (MP). India

Abstract

With the exponential growth of the Internet of Things (IoT), optimizing power consumption has become a critical challenge in ensuring the sustainability and efficiency of connected systems. Traditional power management techniques often rely on static algorithms and fail to adapt to dynamic workloads and environmental changes. This study explores the application of Artificial Intelligence (AI) in optimizing power utilization across IoT devices through intelligent electronic control systems. By integrating machine learning algorithms, real-time analytics, and adaptive control strategies, AI enables predictive power regulation, extending battery life and improving energy efficiency. Experimental results indicate that AI-based optimization can reduce power consumption by up to 35% compared to traditional models. The findings highlight the transformative potential of AI in enhancing the reliability, performance, and scalability of IoT networks for industrial, healthcare, and smart home applications.

Keywords: Artificial Intelligence, IoT, Power Optimization, Machine Learning, Energy Efficiency, Embedded Systems, Predictive Control

Introduction

The proliferation of IoT devices—ranging from wearable sensors to industrial automation systems—has revolutionized data-driven decision-making and real-time monitoring. However, these devices often operate in energy-constrained environments, relying on limited power sources such as batteries or energy harvesting units. Efficient power management, therefore, is crucial to prolonging device life, maintaining reliability, and minimizing environmental impact.

Conventional power management systems employ rule-based or threshold-based approaches, which lack adaptability to dynamic system behaviors. In contrast, AI-driven electronic control systems can analyze real-time data patterns, predict energy demand, and dynamically adjust operational parameters such as voltage, frequency, and transmission intervals. These systems learn from previous usage patterns and optimize power distribution across device components—sensors, processors, and communication modules—based on contextual needs.

This research investigates how AI-enabled power optimization frameworks can significantly reduce energy consumption while maintaining operational performance. The study combines hardware-level power profiling with intelligent control algorithms to design scalable, sustainable, and self-regulating IoT ecosystems.

Methodology

Objectives:

1. To evaluate the impact of AI-based power management in IoT devices.
2. To design a deep learning-based control algorithm for adaptive power regulation.
3. To assess performance gains in terms of energy efficiency and response time.

Research Design:

A hybrid experimental-analytical approach is used. AI models were deployed on IoT testbeds with environmental sensors, wearable devices, and smart home controllers. The system collected performance metrics over 8 weeks, analyzing energy profiles across multiple configurations.

AI Models Used:

- **Reinforcement Learning (RL):** For real-time adaptive power regulation.
- **Deep Neural Networks (DNN):** For workload prediction and behavioral pattern recognition.
- **Support Vector Regression (SVR):** For predictive analysis of energy demand.

Hardware Setup:

IoT devices used: ESP32, Raspberry Pi 4, and ARM-based embedded boards with sensor nodes (temperature, motion, and communication modules).

Evaluation Metrics:

- Average Power Consumption (mW)
- Battery Life (Hours)
- Energy Efficiency Improvement (%)
- Response Latency (ms)
- Model Accuracy (%)

Case Study: Smart Home Automation System (India)

A smart home environment consisting of 20 interconnected IoT devices was selected to test the AI-driven power optimization framework. Devices included smart thermostats, lighting systems, and environmental sensors.

The Reinforcement Learning agent dynamically adjusted device duty cycles based on occupancy detection, ambient light intensity, and temperature variations. The AI system continuously learned user behavior and optimized energy consumption without compromising performance.

Results:

- Average power savings of 32% over baseline.
- Extended battery life of wireless devices by 28%.

- Real-time power control decisions executed within 0.45 seconds.
- Energy wastage during idle states reduced by 40%.

This case demonstrates the practical potential of AI-based predictive energy management in achieving sustainability and cost-effectiveness in residential IoT ecosystems.

Data Analysis

Table 1: Comparative Power Consumption Before and After AI Optimization

Device Type	Baseline Power (mW)	After AI Optimization (mW)	Power Reduction (%)	Battery Life (Hours)
Smart Sensor Node	120	78	35	72
Smart Thermostat	200	135	32.5	68
Lighting Control Unit	150	95	36.7	70
Environmental Monitor	180	120	33.3	66
Communication Hub	250	170	32	80

Interpretation:

AI-driven adaptive systems achieved average energy savings of 33.9% across devices. The most significant reduction was observed in lighting control and sensor modules due to context-aware scheduling and dynamic voltage scaling.

Table 2: Model Performance Comparison for Predictive Energy Management

AI Model	Accuracy (%)	Response Latency (ms)	Energy Efficiency (%)	Scalability Rating (1–5)
SVM	87	2.8	25	3
Random Forest	91	2.4	27	4
Deep Neural Network (DNN)	94	1.8	31	4
Reinforcement Learning (RL)	97	1.2	35	5

Interpretation:

Reinforcement Learning outperformed other models due to its adaptive learning and real-time optimization capabilities. DNN also achieved robust results but required higher computational resources.

Questionnaire

1. How significant is energy optimization in maintaining IoT system reliability?
2. What challenges arise in deploying AI-based power management in low-power IoT environments?
3. Which AI algorithms are most effective for real-time adaptive energy control?
4. How do users perceive AI-optimized IoT devices in terms of responsiveness and performance?
5. What are the potential risks of over-automation in power management systems?

Conclusion

AI-driven power optimization has revolutionized energy management in IoT ecosystems by combining intelligence, adaptability, and sustainability. The integration of machine learning and reinforcement learning algorithms enables IoT devices to autonomously manage power resources while maintaining performance and connectivity.

Experimental results demonstrate substantial improvements in energy efficiency and battery life, confirming AI's pivotal role in reducing operational costs and extending device longevity. However, challenges remain in terms of computational overhead, real-time inference latency, and data privacy.

The study concludes that the future of IoT power management lies in the convergence of AI, edge computing, and adaptive control frameworks. These innovations can ensure scalable, low-power IoT architectures suitable for industrial automation, healthcare monitoring, and smart infrastructure applications worldwide.

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