Editorial

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AI-Driven Process Control: Transforming Modern Biomanufacturing

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Introduction

AI-driven process control refers to the application of artificial intelligence (AI) and machine learning (ML) techniques to monitor, predict, and optimize manufacturing processes in real time. In biomanufacturing, where processes are highly complex and sensitive to variation, maintaining consistent product quality is a major challenge. Traditional control strategies often rely on fixed setpoints and empirical models, which may not fully capture process dynamics [1,2]. AI-driven process control offers a data-centric approach that enables adaptive decision-making, improved process understanding, and enhanced operational efficiency.

Discussion

At the core of AI-driven process control is the use of algorithms capable of learning from large volumes of process data. These models integrate data from sensors, process analytical technologies (PAT), and historical manufacturing records to identify patterns and relationships among critical process parameters. Machine learning techniques such as neural networks, support vector machines, and reinforcement learning can predict process outcomes and recommend control actions before deviations occur [3,4].

One major advantage of AI-driven control is its ability to handle nonlinear and multivariate systems common in bioprocessing. For example, AI models can simultaneously account for interactions between temperature, pH, nutrient concentration, and cell metabolism, enabling more precise control of upstream and downstream operations. Predictive capabilities also support early fault detection, reducing batch failures and minimizing downtime [5].

AI-driven process control aligns closely with quality-by-design (QbD) principles by enhancing process robustness and consistency. Real-time optimization allows processes to operate closer to optimal conditions, improving yield and reducing resource consumption. Additionally, AI systems can continuously adapt to process changes, making them particularly valuable for intensified and continuous manufacturing platforms.

Despite its potential, the adoption of AI-driven process control faces challenges. Data quality and availability are critical, as inaccurate or incomplete data can lead to unreliable predictions. Model interpretability and validation are also important, especially in regulated environments where transparency and traceability are required. Ensuring cybersecurity and integration with existing control systems further adds to implementation complexity.

Conclusion

AI-driven process control represents a significant advancement in biomanufacturing, offering improved process stability, efficiency, and product quality. By leveraging advanced analytics and real-time data, AI enables proactive and adaptive control strategies beyond the capabilities of traditional methods. While challenges related to data management, validation, and regulatory acceptance remain, ongoing technological and methodological developments are accelerating

adoption. As digital transformation continues, AI-driven process control is poised to become a cornerstone of next-generation biomanufacturing systems.

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