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AI-enhanced wastewater treatment process automation

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Motivation

Wastewater treatment plants (WWTPs) are essential for protecting water quality by removing nutrients, organic carbon, and metals from effluents. Stricter discharge limits under the Urban Wastewater Treatment Directive will demand higher treatment performance and up to 40% more energy consumption in thecoming years.

Meanwhile, increasing variability in influent composition and flow, driven by industrial discharges, rainfall, and climate effects, poses new challenges for maintaining stable and efficient operation. This research aims to enable adaptive, data-driven process control through improved sensing and modeling, thereby enhancing the resilience and sustainability of wastewater treatment systems [1].

Technological challenge

The key challenge is the dynamic and complex nature of wastewater systems, where treatment performance depends on bioreactor conditions that fluctuate with influent quality and flow. Mechanistic models, though well established, struggle under such variability, while data-driven models capture dynamics but lackphysical interpretability.

Bridging these approaches requires reliable real-time data and hybrid modeling frameworks. However, limited sensor robustness, high instrumentation costs, and weak digital integration hinder progress. Developing cost-effective monitoring networks and control strategies is essential to ensure stable, energy-efficient, and high-quality treatment performance [2].

Research goals

- Install and operate online sensors to generate high-frequency wastewater process data under real operational conditions.
- Develop hybrid process models combining physics-based descriptions and machine-learning methods for key wastewater treatment dynamics.
- Integrate sensor data and models to improve real-time estimation of process states that are difficult to measure directly.
- Evaluate robustness and reliability of the proposed methods under sensor noise, drift, and changing influent conditions.
- Assess transferability of the approach from an industrial wastewater treatment plant to municipal wastewater treatment plants.

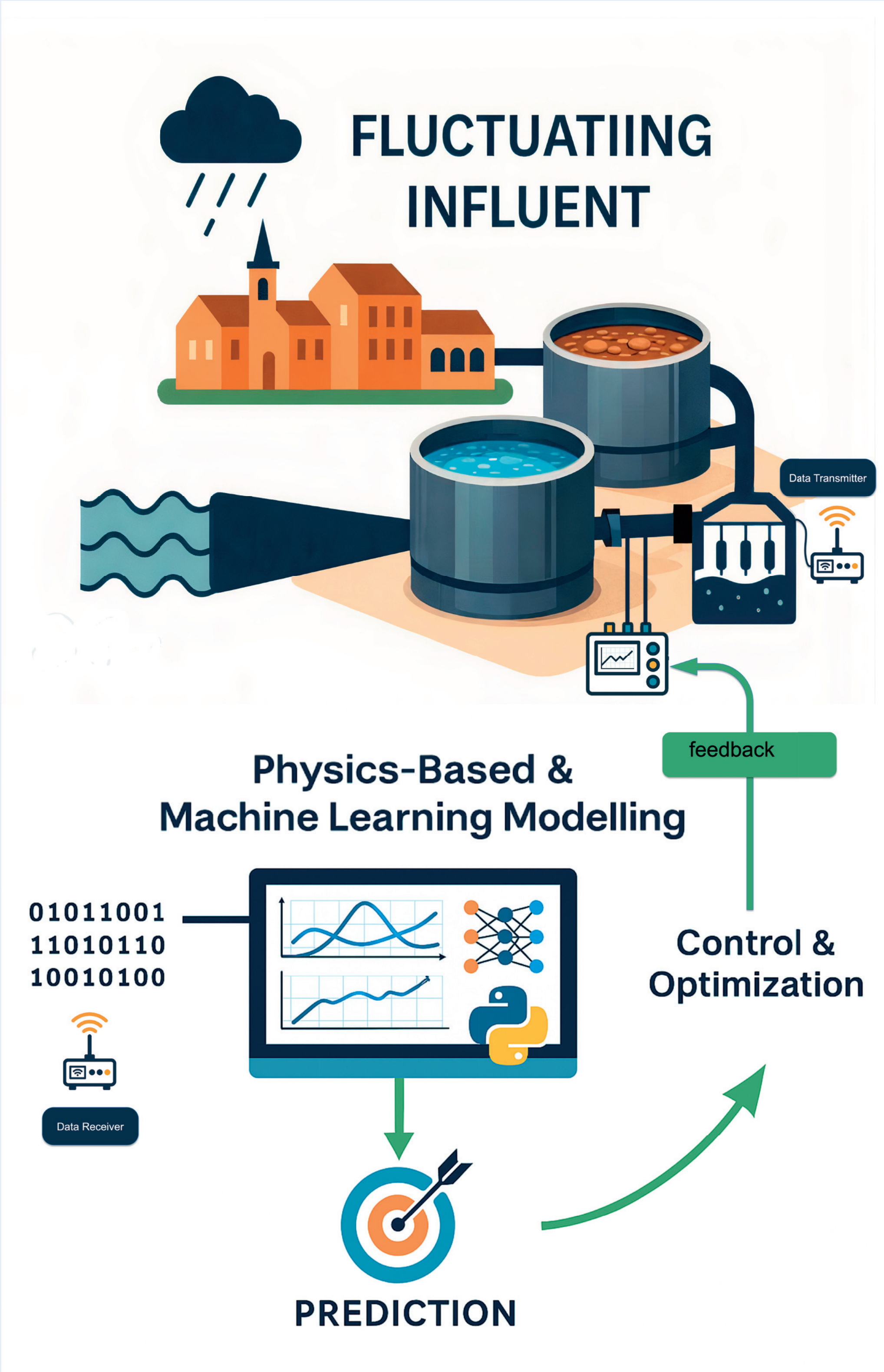

Fig 1. Schematic overview of the AI-enhanced wastewater treatment concept. The upper part shows a conventional WWTP receiving highly variable influent (seasonal changes, rain-induced dilution, industrial discharges) monitored by online sensors. In the lower part, the sensor data stream is collected and processed in a digital environment combining physics-based modelling and machine-learning, generating predictions that are fed back to the plant for real-time optimization and more stable, energy-efficient operation.

References

[1] A.J. Wang et al., Engineering 36 (2024) 21–35.
[2] M.Y. Schneider et al., Water Science and Technology 85 (2022) 2503–2524.

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