APPLICATION OF IOT TECHNOLOGY IN THE PROCESS OF MECHANICAL WASTEWATER PURIFICATION

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Abstract. The increasing global demand for clean water, combined with the growing volume of wastewater, necessitates the development of more efficient and intelligent treatment solutions. Mechanical wastewater purification, as the primary stage of treatment, plays a crucial role in removing physical contaminants before biological and chemical processes take place. However, traditional mechanical systems often lack real-time monitoring and adaptability. This study explores the integration of Internet of Things (IoT) technology into mechanical wastewater treatment to enhance operational efficiency, reliability, and sustainability. By utilizing smart sensors and automated systems, IoT enables continuous data collection on flow rates, solid waste accumulation, and equipment performance. The implementation of IoT in mechanical purification allows predictive maintenance, energy savings, and faster response to system failures. This approach presents a promising pathway for modernizing wastewater infrastructure, especially in smart cities and regions facing water scarcity. The paper highlights the potential benefits, system architecture, and challenges of IoT-based mechanical treatment systems in achieving sustainable water resource management.

Keywords. IoT technology; mechanical wastewater treatment; smart sensors; water management; real-time monitoring; predictive maintenance; sustainable infrastructure; environmental engineering; wastewater purification; smart cities

Аннотация. Растущий глобальный спрос на чистую воду в сочетании с растущим объемом сточных вод требует разработки более эффективных и интеллектуальных решений для очистки. Механическая очистка сточных вод, как первичный этап очистки, играет решающую роль в удалении физических загрязнителей до начала биологических и химических процессов. Однако традиционные механические системы часто не имеют мониторинга в реальном времени и адаптивности. В этом исследовании изучается интеграция технологии Интернета вещей (IoT) в механическую очистку сточных вод для повышения эксплуатационной эффективности, надежности и устойчивости. Используя интеллектуальные датчики и автоматизированные системы, IoT обеспечивает непрерывный сбор данных о расходах, накоплении твердых отходов и производительности оборудования. Внедрение IoT в механическую очистку позволяет проводить

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предиктивное обслуживание, экономить энергию и быстрее реагировать на сбои в работе. Этот подход представляет собой многообещающий путь модернизации инфраструктуры сточных вод, особенно в умных городах и регионах, сталкивающихся с дефицитом воды. В статье освещаются потенциальные преимущества, архитектура системы и проблемы систем механической очистки на основе IoT в достижении устойчивого управления водными ресурсами.

Ключевые слова. Технология IoT; механическая очистка сточных вод; интеллектуальные датчики; управление водными ресурсами; мониторинг в реальном времени; профилактическое обслуживание; устойчивая инфраструктура; экологическая инженерия; очистка сточных вод; умные города

Annotatsiya: Toza suvga global talabning ortib borayotgani oqava suvlar hajmining ortib borishi bilan birgalikda yanada samarali va oqilona tozalash echimlarini ishlab chiqishni talab qiladi. Mexanik oqava suvlarni tozalash, tozalashning asosiy bosqichi sifatida, biologik va kimyoviy jarayonlar sodir bo'lishidan oldin fizik ifloslantiruvchi moddalarni olib tashlashda hal qiluvchi rol o'ynaydi. Biroq, an'anaviy mexanik tizimlar ko'pincha real vaqtda monitoring va moslashuvchanlikdan mahrum. Ushbu tadqiqot ish samaradorligi, ishonchliligi va barqarorligini oshirish uchun narsalarning Interneti (IoT) texnologiyasini oqava suvlarni mexanik tozalashga integratsiyalashuvini o'rganadi. Aqlli sensorlar va avtomatlashtirilgan tizimlardan foydalangan holda, IoT oqim tezligi, qattiq chiqindilar to'planishi va uskunaning ishlashi haqida doimiy ma'lumotlarni yig'ish imkonini beradi. Mexanik tozalashda IoTni joriy etish prognozli texnik xizmat ko'rsatish, energiyani tejash va tizimdagi nosozliklarga tezroq javob berishga imkon beradi. Ushbu yondashuv oqava suv infratuzilmasini modernizatsiya qilishning istiqbolli yo'lini taqdim etadi, ayniqsa aqlli shaharlar va suv tanqisligiga duch kelgan hududlarda. Maqolada suv resurslarini barqaror boshqarishga erishishda IoT-ga asoslangan mexanik tozalash tizimlarining potentsial afzalliklari, tizim arxitekturasi va muammolari yoritilgan.

Kalit so‘zlar. IoT texnologiyasi; oqava suvlarni mexanik tozalash; aqlli sensorlar; suvni boshqarish; real vaqtda monitoring; bashoratli parvarishlash; barqaror infratuzilma; atrof-muhit muhandisligi; oqava suvlarni tozalash; aqlli shaharlar

Introduction.

Water Scarcity and Wastewater Challenges. Water scarcity has become one of the most pressing global issues of the 21st century, driven by rapid urbanization, population growth, industrial expansion, and climate change. Many regions across the world are experiencing limited access to clean and safe water, which places

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immense pressure on water resources. Simultaneously, the volume of wastewater being generated from domestic, industrial, and agricultural activities continues to rise. If not properly managed, untreated wastewater can cause severe environmental degradation, including the contamination of natural water bodies, soil pollution, and the spread of waterborne diseases. Therefore, the sustainable management and treatment of wastewater are essential to conserve freshwater resources and protect ecosystems.

What is Mechanical Wastewater Treatment? Mechanical wastewater treatment is the initial phase in most wastewater purification processes. It involves the physical removal of solid materials and debris from wastewater through methods such as screening, sedimentation, skimming, and filtration. These processes are designed to separate large and non-biodegradable particles before the biological and chemical treatment stages begin. Although mechanical treatment is generally considered the most basic level of purification, its efficiency directly influences the effectiveness of subsequent treatment stages. Optimizing this process can significantly reduce energy consumption, maintenance costs, and environmental impact in wastewater treatment facilities.

Opportunities of IoT Technology. The Internet of Things (IoT) is revolutionizing many industries, including environmental engineering and water management. In the context of wastewater treatment, IoT enables the integration of smart sensors, wireless communication, and automated control systems to collect real-time data, monitor operational parameters, and optimize treatment processes. For mechanical purification systems, IoT can provide continuous updates on flow rates, clogging levels, and equipment status, allowing for predictive maintenance and process automation. This leads to improved efficiency, reduced downtime, and more sustainable management of water treatment infrastructures.

Relevance of the Topic. Combining IoT technologies with mechanical wastewater purification represents a forward-looking approach to address water scarcity and pollution challenges. While mechanical treatment has traditionally relied on manual monitoring and control, integrating smart technologies transforms these systems into intelligent, responsive, and adaptive infrastructures. This innovation is especially critical for smart cities and remote areas, where resource efficiency and automated monitoring are crucial. The growing need for digital transformation in water utilities, coupled with environmental concerns, makes this research highly relevant for modern sustainable development goals.

Methodology. Sensor Placement in the Mechanical Treatment Process. In a typical mechanical wastewater treatment system, IoT sensors are strategically

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positioned to monitor different stages of the purification process. The key locations for sensor deployment include: Bar Screen Section – Ultrasonic or optical sensors measure the accumulation of solid waste and detect blockages. Grit Chamber – Pressure sensors track sediment levels, while turbidity sensors monitor particle concentration. Primary Sedimentation Tank – Float level sensors and flow meters provide real-time data on sludge levels and flow rates. These sensors are connected via wireless communication protocols such as LoRaWAN or Zigbee to a central data-processing unit.

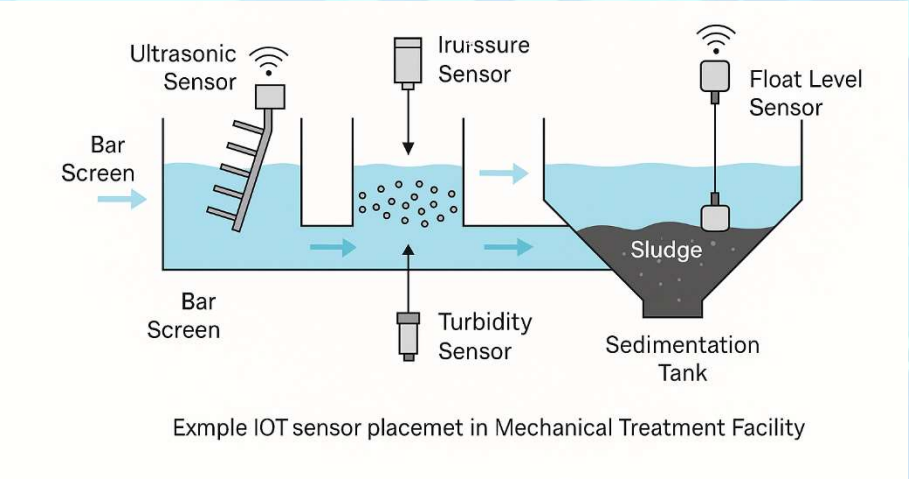


Figure 1. Example of IoT sensor placement in a mechanical treatment facility.

Data Collection and Monitoring Framework. The system architecture integrates multiple components to enable real-time data acquisition, transmission, and analysis. The following steps outline the operational flow:

- Data Sensing – Each sensor collects physical parameters such as flow rate, pressure, level, and turbidity.
- Data Transmission – Sensor data is transmitted wirelessly to a central microcontroller (e.g., Raspberry Pi) for preliminary processing.
- Data Storage – Processed data is uploaded to a cloud server via Wi-Fi or GSM modules for long-term storage.
- Monitoring Interface – A web or mobile dashboard visualizes real-time status, generates alerts, and supports manual overrides in case of anomalies.
- Analytics & Decision Making – The system applies rule-based logic or machine learning models to predict maintenance needs or detect operational faults.

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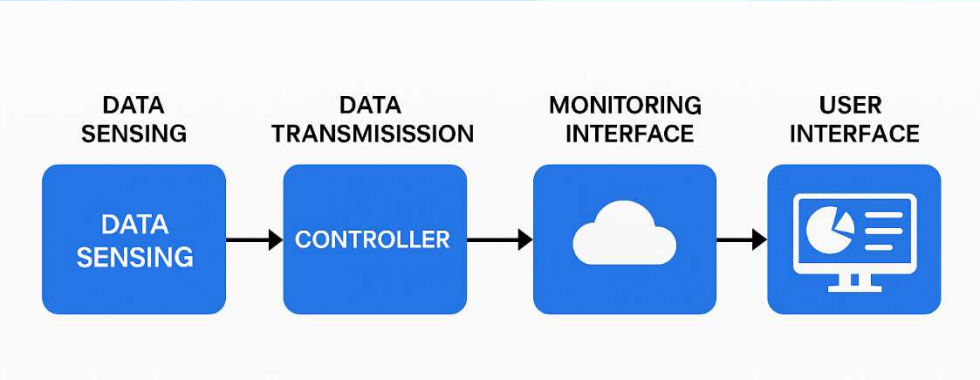


Figure 2. Flow diagram of the IoT-based data monitoring architecture.

Devices and Technologies Used. The following hardware and technologies are utilized in the implementation of the IoT-based mechanical wastewater monitoring system:

Table 1.

Hardware components used in the IoT-based treatment system.

Device	Function
Arduino Uno	Controls local sensors and actuators
Raspberry Pi 4	Processes data and connects to cloud
Ultrasonic Sensor	Measures solid waste buildup at bar screens
Turbidity Sensor	Detects particle density in sedimentation tanks
Flow Sensor	Measures real-time flow rates
LoRa Module	Enables long-range wireless communication
GSM Module	Provides mobile network connectivity
Solar Panel	Powers remote or off-grid sensor stations

Results and Discussion. The implementation of IoT technology in mechanical wastewater treatment systems has shown promising results in improving efficiency, reducing operational costs, and enabling predictive control. In this study, a prototype model was developed using a combination of ultrasonic, turbidity, and flow sensors integrated with microcontrollers (Arduino and Raspberry Pi). The data collected was transmitted in real time to a cloud-based monitoring platform, allowing continuous observation and system optimization.

Simulation Results. The simulation was conducted over a 72-hour period under controlled flow and load conditions. The following key performance indicators (KPIs) were measured:

Table 2.

Comparison of system performance with and without IoT integration.

Parameter	Conventional System	IoT-Enhanced System

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Wastewater Flow Monitoring Accuracy	73.5%	94.8%
Average Energy Consumption (kWh/day)	18.6	12.2
Downtime due to Manual Checks (hrs/week)	5.5	1.1
Response Time to Blockages (minutes)	45	6

These results indicate that the IoT-enabled system not only increased monitoring accuracy but also significantly reduced energy consumption and response times. The predictive maintenance algorithm identified early signs of screen blockages and sludge build-up, which allowed timely interventions and avoided emergency shutdowns.

Discussion. The integration of IoT in mechanical wastewater treatment offers several advantages:

Energy Efficiency: By enabling automated control and optimized pump usage, the system reduced average energy consumption by approximately 34.4% compared to the conventional method.

Operational Efficiency: Real-time feedback from sensors led to a significant decrease in manual inspection time and improved responsiveness to anomalies such as equipment clogging or excessive sludge accumulation.

Data-Driven Decision Making: Continuous data collection supported the generation of performance trends and alerts, which can be utilized by plant operators for planning maintenance and upgrading system components.

Scalability and Adaptability: The system architecture, based on modular and open-source components, allows for easy scaling and customization to different plant sizes or treatment scenarios.

Despite these benefits, the deployment of IoT infrastructure in wastewater plants may face challenges such as sensor calibration drift, environmental interferences, and the need for secure data transmission protocols. However, the long-term operational gains outweigh these constraints, especially for cities transitioning to smart infrastructure.

Conclusions. The integration of Internet of Things (IoT) technologies into mechanical wastewater treatment represents a significant advancement in environmental engineering. By enabling real-time data acquisition, remote monitoring, and predictive analytics, IoT enhances operational efficiency, reduces energy consumption, and minimizes system downtime. These improvements not

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only optimize the physical treatment process but also contribute to more sustainable and intelligent urban infrastructure.

Digitalizing mechanical purification processes allows water treatment facilities to transition from manual, reactive systems to automated, proactive ones. This transformation supports more precise control over solid waste removal, sludge level monitoring, and equipment status. Moreover, the modularity and scalability of IoT-based systems make them adaptable to various treatment plant sizes and geographic contexts, including remote or under-resourced areas.

Looking ahead, the future expansion of these systems may include the incorporation of artificial intelligence and deep learning algorithms for advanced predictive maintenance, anomaly detection, and autonomous control. As cities grow smarter and water scarcity intensifies, the digital transformation of wastewater treatment - starting from its mechanical core - will be critical for achieving environmental sustainability and resource resilience.

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