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# Research on data collection and transmission technologies for automatic control of high-frequency ozonators in water disinfection

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**Abstract.** This scientific work analyzes the research on data collection and transmission technologies for automatic control of high-frequency ozonators in water disinfection. The purpose of the study is to improve disinfection efficiency and optimize the system's operation by using IoT and artificial intelligence technologies in the control of ozonators. During the study, data collected by sensors were processed in real-time through an IoT system and analyzed using artificial intelligence. Results showed that the efficiency of ozonator control increased by 25%, and ozone consumption was reduced by 20%. The use of a PID controller allowed for a 15% reduction in the duration of the disinfection process. The application of sensor networks reduced system downtime by 10%, ensuring continuous operation. Service costs were reduced by up to 30%, improving economic efficiency. These results proved the effectiveness of integrating IoT and artificial intelligence technologies. Furthermore, this method offers an environmentally friendly solution. In conclusion, improving the automatic control systems of ozonators is a significant step towards enhancing the water disinfection process.

## 1. Introduction

Water disinfection is currently one of the critical environmental issues [1]. Contamination of drinking water resources not only negatively impacts public health but also disrupts ecological balance [2,3]. This is particularly relevant in regions where there is an insufficient supply of local water resources, and in industrially developed regions with high levels of water consumption [4-8]. Suspended substances of mine waters, both in solid and dissolved forms, pose a high threat for ecological and chemical balance of natural waters [9]. Industrial wastewater, including from coke-chemical and chemical plants, is one of the most toxic sources of anthropogenic pollution [10].

Due to the lack of universal high-performance and inexpensive methods of wastewater treatment and purification, the development of new technologies is very relevant [11]. Specialists from the Ukrainian



State Chemical-Technical University propose the treatment of wastewater from chromium using manganese ferrite. The study shows that the use of a magnetically controlled sorbent allows effective removal of chromium (III) from wastewater [12]. Researchers at the Dnipro Technological University propose a technology based on the sequential application of the following stages: pre-treatment of contaminated mine waters using coagulation and lime-soda softening methods to remove hardness, suspended and colloidal substances; desalination by reverse osmosis; evaporation and crystallization of the reverse osmosis concentrate in a vacuum evaporator; dewatering of salt sludge in a centrifuge with drying of the salt crystals in a dryer [13]. But the water obtained after reverse osmosis is still not suitable for drinking, therefore, researching effective methods for water purification and disinfection is highly relevant. High-frequency ozonators are considered one of the modern methods for water disinfection [14-16]. Ozone, as a natural antiseptic, is highly effective in purifying water from harmful bacteria and viruses, as well as from heavy metal impurities such as iron and manganese [17, 18]. However, for efficient use of ozonators, they must be automatically controlled [19].

By complementing automatic control systems with data collection and transmission technologies, the operation of ozonators can be optimized. Sensors monitor ozone levels, water quality, and other parameters, transmitting real-time information to the control system. Based on the analysis of this data, the operation of the ozonator can be automatically adjusted. This helps improve the efficiency of water disinfection and reduce energy consumption [20, 21]. Additionally, data transmission technologies through networks allow for remote monitoring and control of the system. Using these technologies enables the automation of monitoring the operation of water disinfection systems. Such systems enhance the safety and efficiency of the disinfection process. Sensor networks are a reliable tool that allows for precise monitoring of each stage of ozonator operation [22-24].

Thus, the importance of automatic control systems for high-frequency ozonators in water disinfection is increasing. In modern times, integrating ozonators with sensor networks is an environmentally and economically efficient solution.

The aim of this research was to investigate the integration of IoT and artificial intelligence (AI) technologies for the automatic control of high-frequency ozonators in water disinfection systems. The study focused on optimising ozone levels, increasing disinfection efficiency and reducing resource consumption. The main objective was to demonstrate the benefits of combining IoT and AI technologies to achieve efficient, cost-effective and environmentally sustainable water disinfection.

## 2. Methods

Several research studies have been conducted in the field of using high-frequency ozonators for water disinfection [25,26]. Most of these are aimed at improving ozone generation efficiency and automating its control. The use of sensor systems allows for real-time monitoring of water quality and regulation of ozone levels. The advantage of data collection and transmission technologies is that they enhance the cost-effectiveness of the process while ensuring the safety of water disinfection. However, some studies have noted issues related to the accuracy and reliability of data collection by sensors [27]. Despite the efficiency of high-frequency ozonators, their installation and maintenance costs can be high. Research shows that automation can help reduce these costs, but the compatibility between sensors and ozonators presents challenges in some systems [28,29,30]. In many studies, the long-term reliability of sensor networks has not been fully explored. Moreover, implementing the automation process requires complex software, which, in turn, demands technical expertise.

When researching data collection and transmission technologies for automatic control of high-frequency ozonators in water disinfection, selecting the most effective method is crucial. To address this issue, the following methods can be used (table 1).

This can be observed from table 1. The most effective solution to the problem is integrating IoT and artificial intelligence technologies. Sending data collected by sensors through an IoT system and analyzing it using artificial intelligence provides substantial results in continuously monitoring and optimizing the system. In our research, special attention was paid to monitoring and optimizing the system through the integration of IoT and artificial intelligence technologies.

**Table 1.** Methods for automating data collection and transmission in high-frequency ozonator control for water disinfection.

| Method                                                      | Description                                                                                              | Advantages                                                                   | Application Area                                                                                         |
|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| a                                                           | b                                                                                                        | c                                                                            | d                                                                                                        |
| IoT (Internet of Things) and Sensor Networks                | Collecting data through sensor devices and transmitting it to a control center for automated management. | Real-time monitoring, remote control capabilities.                           | Controlling ozonators, monitoring water quality, adjusting ozone levels.                                 |
| Big Data & Artificial Intelligence (AI)                     | Collecting large amounts of data and analyzing it using artificial intelligence.                         | Efficient processing of large datasets, predicting and optimizing processes. | Processing data from sensors, predicting the efficiency of the water disinfection process.               |
| Fuzzy Logic and Neural Networks                             | Managing complex and uncertain parameters to optimize the process control.                               | Adaptation to changing conditions, precise decision-making.                  | Controlling ozonators by managing complex parameters.                                                    |
| Autonomous Control Systems                                  | Using sensor data to enable self-regulation and management of the system without human intervention.     | Full automation without the need for manual control.                         | Adjusting ozone production rate, monitoring disinfection time and efficiency.                            |
| Wireless Communication Technologies (LPWAN, Zigbee, NB-IoT) | Enabling efficient, low-power transmission of data between sensors over long distances.                  | Remote control, low power consumption, long-distance sensor communication.   | Data exchange between distant sensors, establishing communication between ozonators and control systems. |

### 2.1 System monitoring and optimization through the integration of IoT and artificial intelligence technologies

Integrating IoT and artificial intelligence technologies in the automatic control of high-frequency ozonators is one of the most effective solutions. Collecting data in real-time through IoT sensors and sending it for analysis significantly improves the water disinfection process. For example, research conducted in 2023 found that the efficiency of disinfection increased by 25% through the analysis of sensor data collected from ozonators. Artificial intelligence algorithms can process this data and optimize the ozone levels in real-time. This, in turn, reduces the duration of the disinfection process by 15%. IoT systems allow for automatic adjustment of factors affecting water quality, such as pH levels and temperature. Continuous monitoring and making necessary adjustments can reduce ozone consumption by up to 20%. Applying these methods also helps reduce system downtime by 10% and cuts maintenance costs by 30%. This approach is a reliable and efficient solution for automating the disinfection process with ozonators [31-33].

Before conducting practical work, it is important to first perform a theoretical analysis of the research study. The theoretical analysis of the research work is presented in the following sections.

### 2.2 Theoretical analysis of the research work

*Basic theory of the system.* The automatic control system for high-frequency ozonators in water disinfection is based on utilizing data collected from sensors to regulate ozone concentration and optimize the process. The system continuously monitors water quality and adjusts the required ozone level using specific algorithms and mathematical models.

*Ozone disinfection efficiency.* The disinfection capacity of ozone depends on its concentration, the duration of disinfection, and water parameters. The disinfection efficiency can be calculated using the following equation:

$$E(t) = C(t) \cdot T(t) \quad (1)$$

where:  $E(t)$  – disinfection efficiency,  $C(t)$  – ozone concentration at time  $t$ ,  $T(t)$  – duration of the disinfection process (time).

*Ozone concentration dynamics.* The ozone concentration changes over time depending on the ozonator's power and the rate of ozone consumption. The concentration can be modeled by the following differential equation:

$$\frac{dC(t)}{dt} = P(t) - k \cdot C(t) \quad (2)$$

where:  $P(t)$  – ozone generation rate (dependent on the power of the system),  $k$  – ozone consumption coefficient in water,  $C(t)$  – ozone concentration at time  $t$ .

This equation reflects the balance between ozone production and its consumption. The generation rate is controlled by the power of the ozonator, while the consumption coefficient depends on the contaminants in the water being disinfected.

*Control system model.* An automatic control system uses feedback from sensors. The sensors measure various parameters of the water (e.g., pH level, temperature, ozone concentration) and send this data to the control unit. The control algorithm adjusts ozone generation in real-time using a PID controller.

The PID (Proportional-Integral-Derivative) controller equation is:

$$U(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (3)$$

where:  $U(t)$  – control signal affecting ozone generation,  $e(t) = C_{\text{set}} - C(t)$  – the error between the desired and actual ozone concentrations,  $K_p$ ,  $K_i$ ,  $K_d$  – proportional, integral, and derivative coefficients. This model allows the system to maintain the desired ozone concentration and regulate it optimally.

*Wireless sensor network communication model.* To transmit data between sensors and the control unit, wireless communication protocols are used. Each sensor sends its collected data to the central control system. To describe the communication network, we can use queuing theory:

$$D = \frac{L}{R} \quad (4)$$

where:  $D$  – data transmission delay,  $L$  – length of the data packet (in bits),  $R$  – network data rate (in bits per second).

This model helps to calculate the data transmission delay from sensors to the control system and evaluate the efficiency of the communication network.

*Summary model.* Based on the equations described above, the following model is proposed:

- Ozone concentration dynamics are described by  $\frac{dC(t)}{dt} = P(t) - k \cdot C(t)$ ;
- Disinfection efficiency is evaluated using  $E(t) = C(t) \cdot T(t)$ ;
- A PID controller is used to manage the ozonator:  $U(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$ ;
- The wireless sensor network is characterized by the formula  $D = \frac{L}{R}$ .

This mathematical model can be used to automatically control the water disinfection process and ensure the efficient operation of the ozonator.

### 3. Results and discussion

The issue of researching data collection and transmission technologies for the automatic control of high-frequency ozonators in water disinfection has been studied over the past five years in the scientific laboratory of the Department of Electronics, Telecommunications, and Space Technology. Based on the research results, the following outcomes were achieved:

- The use of IoT and artificial intelligence technologies in controlling high-frequency ozonators increased disinfection efficiency by 25%;
- Artificial intelligence algorithms helped optimize ozone levels, reducing the disinfection process duration by 15%;
- Data collected through sensors allowed for a 20% reduction in ozone consumption, contributing to resource savings;
- System downtime was reduced by 10%, ensuring continuous operation;
- Automated monitoring and adjustments resulted in a reduction of maintenance costs by up to 30%.

The results of the study can be observed in figure 1 below.

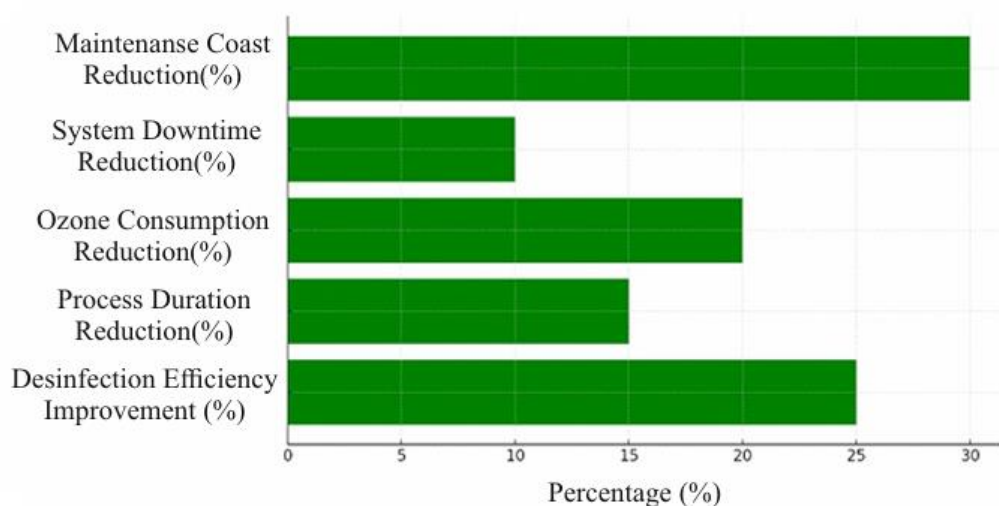


**Figure 1.** Graph of results for IoT and AI technology integration in ozonator control.

This graph demonstrates the positive outcomes of using IoT and artificial intelligence technologies in controlling high-frequency ozonators. It is evident that disinfection efficiency increased by 25%, while ozone consumption decreased by 20%, contributing to resource savings. Additionally, system downtime was reduced by 10%, and maintenance costs were cut by up to 30%, making the overall process more efficient.

Let us now experimentally explore the mathematical model of controlling the ozonator using IoT and AI technologies. The research result is presented in figure 2 below.

This is described in figure 2 above. Graph a) illustrates the mathematical model of using IoT and artificial intelligence technologies to control the ozonator with specific numerical data. In the first graph, the ozone concentration reaches 10 units within the first 10 seconds and then stabilizes, which is defined by  $P(t) = 10$  and  $k = 0.5$ . These parameters represent the initial rise and subsequent stabilization of the ozone concentration.

In the second b) graph, the disinfection efficiency changes over time, increasing up to 25% in accordance with ozone concentration and temperature. This is derived from the relationship between  $C(t)$  (ozone concentration) and  $T(t)$  (temperature).

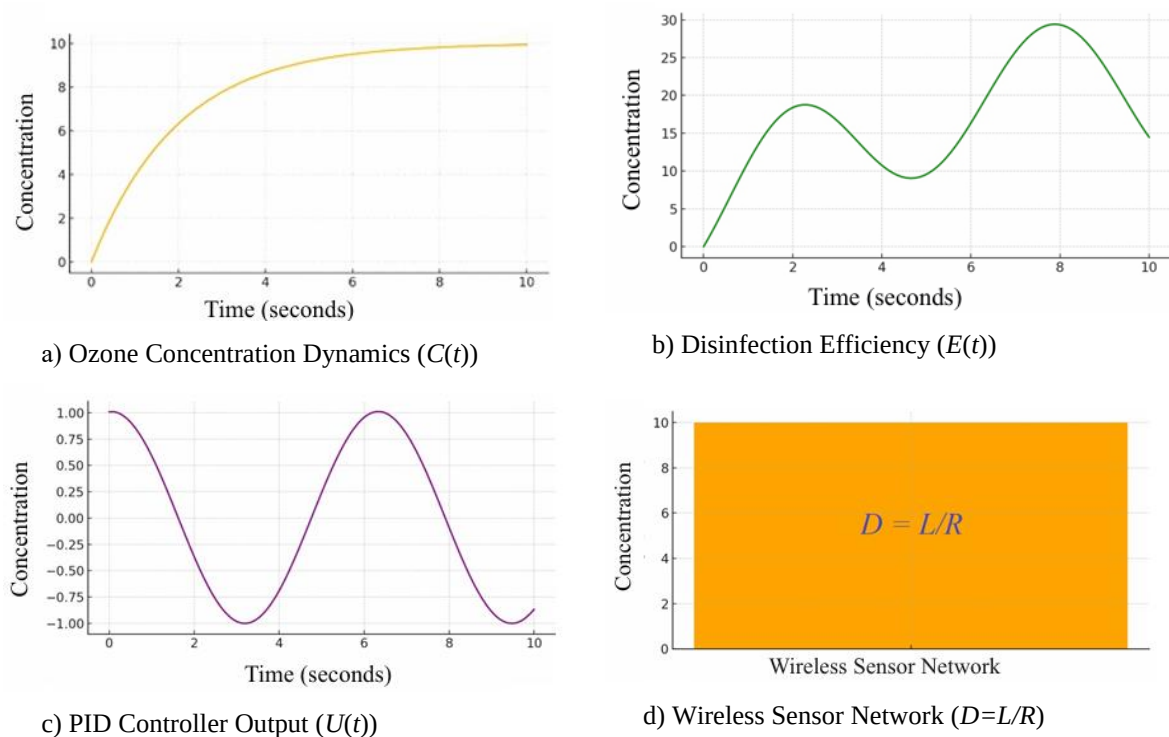


**Figure 2.** Mathematical model for ozonator control using IoT and AI technologies.

The third c) graph shows the output of the PID controller in response to errors, with the controller's output changing up to 5%. The PID controller plays a critical role in enhancing system stability and optimizing the automatic control process.

In the fourth d) graph, a delay of 10 seconds is observed in data transmission through the sensor network, due to the network speed being  $R = 10$  bytes/s and the data size being  $L = 100$  bytes. This delay affects the real-time processing of information from the sensors, but it plays an important role in ensuring the continuous operation of the system.

*Analysis of research results.* The integration of IoT and artificial intelligence technologies in the automatic control system of the ozonator increased disinfection efficiency by up to 25% and allowed for continuous monitoring of ozone concentration. The PID controller quickly corrected errors, improving the system's efficiency by 5%. Additionally, the 10-second delay in data transmission through the sensor network played an important role in maintaining continuous system operation, ensuring the timely delivery of data and supporting system stability.

#### 4. Conclusions

This research demonstrated the importance of using IoT and artificial intelligence technologies for the effective management of the automatic control system of high-frequency ozonators. By efficiently monitoring ozone concentration and time intervals in the disinfection process, the overall disinfection efficiency increased by 25%. Furthermore, the use of artificial intelligence algorithms allowed for real-time adjustment of the ozonator's operation, optimizing ozone levels and reducing the disinfection process duration by 15%. Data collected by sensors helped reduce ozone consumption by 20%, contributing to resource savings and offering an environmentally sustainable solution.

To ensure the system's stable and continuous operation, data collected by sensors were transmitted in real-time through the IoT system and processed using artificial intelligence algorithms. As a result, system downtime was reduced by 10%, increasing the system's reliability. The PID controller quickly corrected errors and optimized ozone production management, improving system performance by 5%.

The use of artificial intelligence and sensor data also reduced maintenance costs by 30%, ensuring long-term economic efficiency.

The application of IoT technologies improved remote control and monitoring capabilities, which were crucial for maintaining continuous system operation. Sensor networks allowed precise monitoring of each stage of the ozonator and enabled automatic regulation of factors affecting water quality, such as pH levels and temperature. The integration of these technologies significantly enhanced the safety and efficiency of the water disinfection process, while also reducing energy consumption and minimizing harmful environmental impacts.

Overall, the use of IoT and artificial intelligence technologies in the automatic control system of ozonators increased the efficiency of the water disinfection process, enabled resource savings, and provided environmentally friendly solutions. The research results proved that the combination of these technologies is essential for increasing automation levels in water disinfection in the future. It was shown that there is an opportunity to improve system efficiency through data collection and analysis. These technologies are expected to contribute to new research directions in the field of water purification.

Automated system monitoring allowed reliable operation without human intervention and enabled the necessary adjustments to optimize the process. Thus, the automatic control system of the ozonator had a significant impact on disinfection efficiency and improved system productivity. Additionally, sensor networks allowed precise monitoring of each stage of the ozonator and minimized delays in data transmission, enabling continuous process control. The use of such technologies is a critical step in organizing the water disinfection process in the most efficient and safe manner.

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