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AUTOMATIC CONTROL AND ARTIFICIAL INTELLIGENCE: DEVICE FOR CONTINUOUS CHLORINE RESIDUAL MEASUREMENT

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Abstract: Bacteriologically safe water is crucial for potable and food production, which is obtained using disinfection. Disinfectants must be broad-spectrum, act swiftly, withstand organic matter, maintain stability across pH levels, be non-toxic, minimally corrosive, and pleasant-smelling. Precise dosing is vital, typically achieved via automated membrane dosing pumps, and is ensured by measuring residual chlorine post-disinfection. This paper introduces devices utilising amperometric electrodes to maintain active chlorine levels of 0.2 to 0.5 mg/l. Industrial computer and touch panel aid data storage and visualisation, enabling performance prediction via machine learning. Deployed at the dairy company Kozanostra in Osečina, it's a major water safety advancement.

Keywords: water quality, disinfection, automation, machine learning, artificial intelligence

Introduction

Drinking water must be free from pathogenic microorganisms in order for it to be safe for consumption. As most water sources fall short, it's necessary to implement appropriate measures to ensure water becomes bacteriologically

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safe. Continuous disinfection is crucial, preventing waterborne diseases like typhoid, paratyphoid, dysentery, etc. Continuous disinfection is essential for well water, springs, reservoirs, swimming pools, septic tanks, industrial wastewater outflows, and sewage. Different water supply systems require specific disinfection devices. Chemical disinfectant addition generally involves gravitational drainage or pressurised methods. Amperometry, an electrochemical technique, measures hypochlorite ion reduction to regulate disinfectant dosage for maintaining optimal levels. This method directly measures free chlorine concentration and incorporates a continuous hydraulic cleaning system to minimise calibration needs, ensuring efficient operation. The limiting current of reduction on the rotating disk electrode can be calculated from the following equation:

$$j_g = 0.620 z F C_O D^{2/3} \nu^{-1/6} \varpi^{1/2}$$

where ϖ is angular velocity, ν is kinematic viscosity, D is the diffusion coefficient, C_O is concentration of hypochlorite at the depth of the solution, z is number of exchanged electrons in the reaction, and F is Faraday's constant, which is $9{,}65 \cdot 10^4$ C/mol.

Also, an essential component is a measuring probe, which is a cell responsible for assessing residual chlorine levels post-dosing and then regulating dosing intensity after. The addition of disinfectants, mostly chlorine, into the pipeline is carried out by dosing pumps or injectors. The residual chlorine values are maintained at from 0.2 to 0.5 mg/l.

In the case of the presence of nitrogen compounds such as ammonia in the water, free chlorine reacts with them to form chloramines (monochloramine NH_2Cl, dichloramine $NHCl_2$, trichloramine NCl_3), which are called combined chlorine (bound chlorine). The sum of free and combined chlorine constitutes total chlorine.

Equipment for automatic control of the water disinfection process consists of the following elements: inlet pipeline, equalisation tank (hydropneumatic tank), outlet pipeline, measuring element - sensor on the outlet pipeline, controller that converts the measured value from the sensor into an electrical signal and activates and deactivates the actuator (dosing pump) that introduces hypochlorite into the inlet pipeline. The block diagram of such a device with negative feedback where the system output follows the specified input parameters is shown in Figures 1.

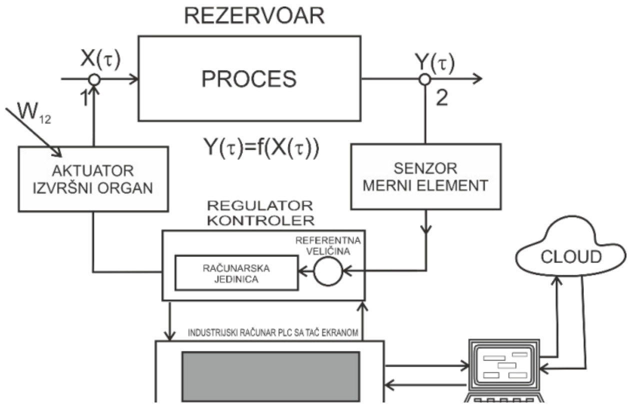

Figure 1. Block diagram of a negative feedback control system

The device for measuring chlorine content in water is used to measure and store the data in a database. Based on the operational history of measured parameters over an extended period of several months, it is possible, with the help of machine learning and neural networks, to forecast the operation of such systems in the future. The block diagram of such a system is given in Figure 2.

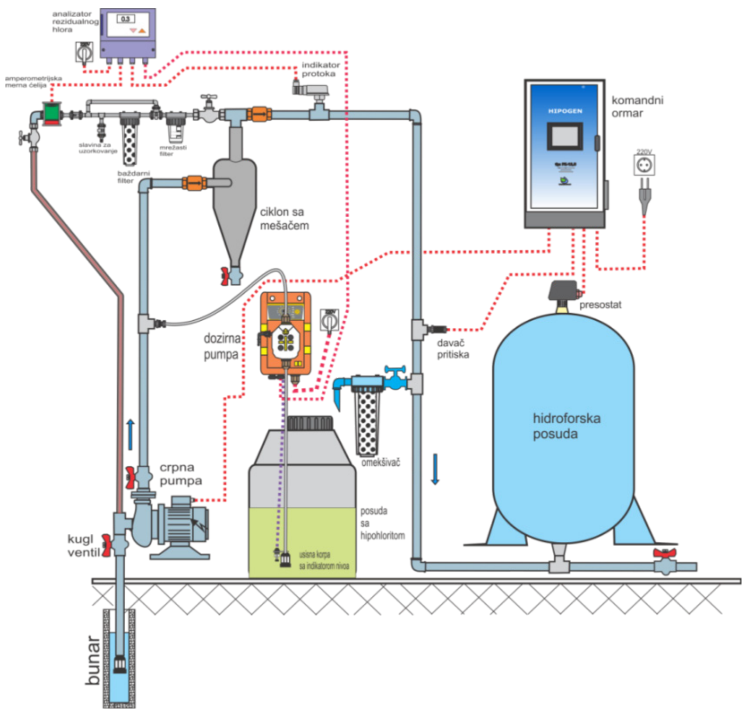

Figure 2. Water disinfection system with operational history and AI

Materials and methods

The device for measuring chlorine content in water consists of: Controller LDSCL (ERMES COMMUNICATION), LCD monitor WEINTEK cMT2078X, LC controller DELTA DVP-14SE. The LDSCL controller measures chlorine levels in water from 0 to 10 mg/l, displayed on an LCD screen. Adjustments are made via a multifunctional button. Housed in a plastic IP65-rated enclosure, it transmits data to an LCD HMI monitor via RS485, ModBUS RTU. Values are stored in the monitor's memory and can be viewed locally or on a PC via ETHERNET. Communication with the PLC controller activates the electromagnetic valve for water flow through the sensor.

The screen displays chlorine content and valve status (green "light" VALVE). Data can be viewed in tabular or graphical form, accessed via "GRAPHICAL VIEW" or "TABLE VIEW" buttons, as shown in Figure 3. The valve opens hourly from 5:00 AM for 10 minutes. Measurements are recorded every minute for 5 minutes after the flow begins. Data in the table includes measurement number, time, date, and chlorine content.

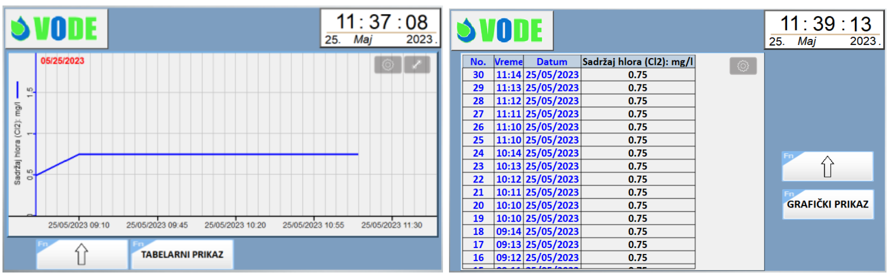

Figure 3. Graphical (left) and tabular (right) representations of obtained results

The LCD monitor can be connected to a PC in a local network. To establish communication between the computer and the LCD HMI monitor, the devices must be connected with a network cable with RJ45 connectors at both ends, and the IP addresses of both devices must be set in the same address range. The cMTViewer program needs to be installed on the PC. By running the program and configuring the IP address on the monitor, the PC will display the figure from the LCD HMI monitor.

Once communication between the LCD HMI monitor and the PC is established, all screens can be displayed on the PC just like on the LCD HMI monitor. Files with the archive of measured values can be copied from the PC to the remote computer.

Figure 4. Device for measuring residual chlorine with automatic control and AI

Results and discussion

The study analyses chlorophyll concentrations empirically using a dataset of 21,271 observations spanning from June 2023 to February 2024. The data undergoes preprocessing to normalise values and refine temporal granularity to 12-hourly averages.

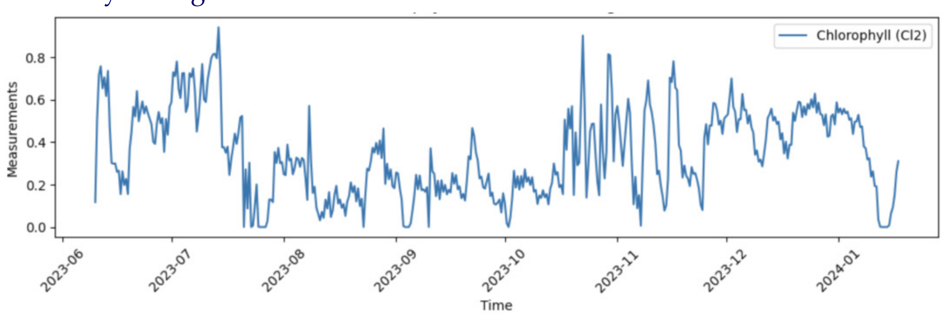

Figure 5. Chlorophyll Cl_2 (mg/l) over time

Three models are applied: Long Short-Term Memory (LSTM), Gradient Boosting Regressor, and Autoregressive Integrated Moving Average (ARIMA). They are evaluated based on predictive accuracy and ability to capture temporal patterns.

Table 1. Model Performance Comparison

Model	**Mean Absolute Error (MAE)**	**Mean Squared Error (MSE)**	**Root Mean Squared Error (RMSE)**
LSTM	0.1725	0.0377	0.1943
Gradient Boosting	0.0913	0.0197	0.1403
ARIMA	0.0747	0.0125	0.1118

In chlorophyll concentration forecasting using time series data, ARIMA model demonstrates superior performance, with lowest MAE, MSE, and RMSE values, indicating effective capture of temporal patterns. Gradient Boosting also performs well in handling non-linear patterns, surpassing LSTM. The latter's lower performance suggests complexity and potential overfitting issues. These findings stress the importance of model selection tailored to dataset characteristics. For this task, ARIMA's focus on temporal patterns yields the most reliable predictions.

Conclusion

Based on the presented results, it can be concluded that:

1. The device for continuous measurement of residual chlorine with automatic control and artificial intelligence is a functional solution and has been operating in exploitation for several months.
2. Chemical analysis of the outlet water shows that the quality of the obtained water meets the Regulations on the Chemical and Bacteriological Potability of Drinking Water and that the water can be used in households.
3. Thanks to machine learning and neural networks, the device predicts the future operations of the system and informs the user about future material and energy requirements necessary for the device operation.
4. With the bacteriologically and chemically safe water, and continual monitoring system of the drinking water quality, the dairy company

Kozanostra in Osečina has acquired the necessary conditions for exporting its products like cheese, yogurt, and powdered whey.

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