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DESIGN OF WIRELESS WATER QUALITY MONITORING SYSTEM FOR WATER TREATMENT FACILITIES

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ABSTRACT

In this article, a system for monitoring water quality parameters based on a network of wireless sensors has been developed to improve the accuracy of measuring water quality in real time. The system consists of a water quality parameters collection terminal, a distributed sensor network, a Transmission Control Center base station and a remote online monitoring system. Parameters accumulation terminal dumps the water quality parameters and transmits them to the central base, then sends them back to the remote online monitoring center via GPRS and adjusts the water quality, pH (potential hydrogen) and DO (dissolved oxygen) to the parameters to be entered from the user's side. The results show that the required parameters of the measurement accuracy are 2,1%, 1,3% and 3,6%, respectively, the measurement error of temperature, pH and DO, and the Maximum error of the dissolved oxygen value is 1,9%, 2,6% and 3,1%. The whole system works stable and reliable.

KEYWORDS: *water quality monitoring, distributed wireless network, digital filtering algorithm, particle optimization algorithm; PID controller.*

INTRODUCTION

Water resources are important and the basis for the development of the national economy and are associated with the security and standard of living of people. With the development of the economy of the Republic of Uzbekistan and the improvement of people's living standards, wastewater discharge is increasing day by day, and the wastewater treatment industry is facing huge challenges. The process of wastewater treatment is that the water after a certain treatment must meet the established regulatory standards and the water after treatment can be used in reservoirs [1-4].

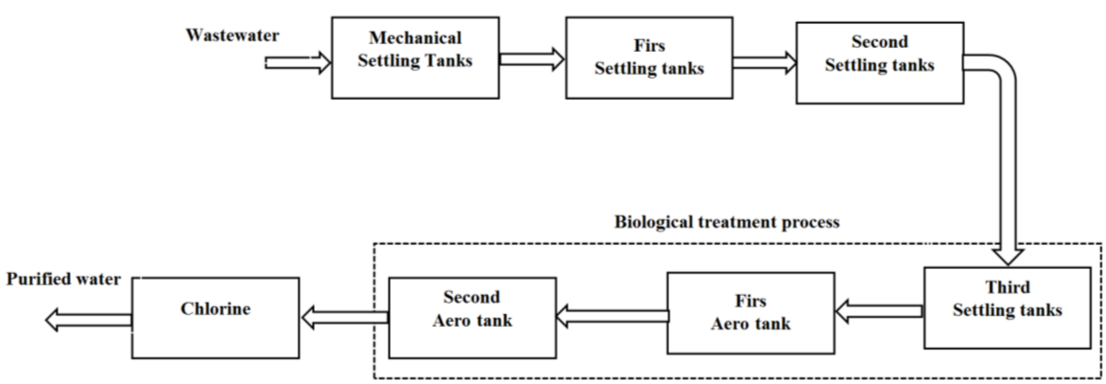

Figure 1. Block diagram of the wastewater treatment process.

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The main process of wastewater treatment begins with the fact that wastewater enters the sewer facilities and is treated in the following sequence.

SYSTEM STRUCTURE

Due to the manual control in the existing water quality monitoring system, there are many shortcomings, and the adjustment accuracy is low. In Fig. 2, taking into account the existing shortcomings, a water quality measurement and control system is proposed that applies distributed wireless network technology and remote control technology to a water quality monitoring system in a water treatment plant.

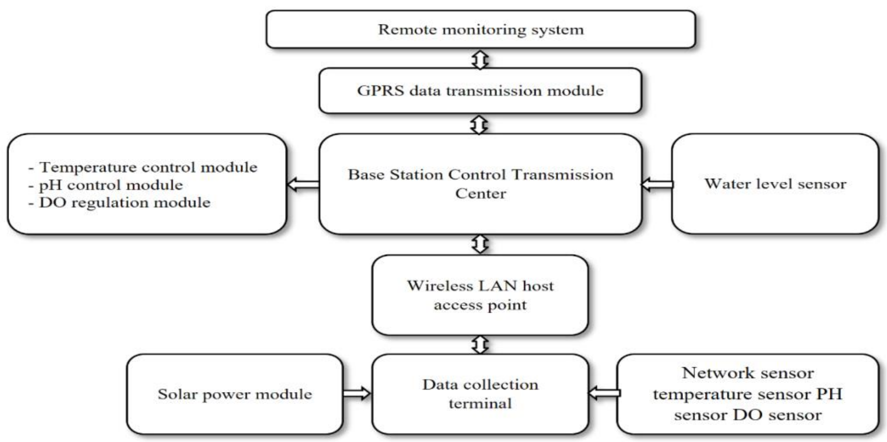

Figure 2. Structural diagram of a wireless water quality monitoring system.

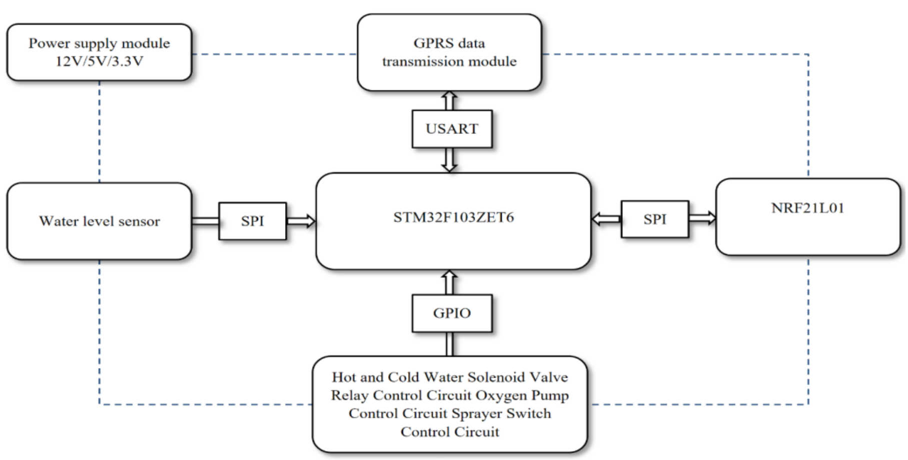

Figure 3. Block diagram of the hardware of the base station of the transmission control center and the data collection terminal.

The system realizes the measurement and control of water quality parameters and transmits to the remote monitoring system through a wireless network to control water in real time. The base station of the control center is mainly used to connect the remote monitoring system and data collection terminal, and execute the commands of the remote monitoring system; the data collection terminal is mainly responsible for collecting water quality parameters and sending the data to the base station of the transmission control center. Fig. 2 and 3, respectively, show a block diagram of the hardware of the base station of the transmission control center and the data collection terminal [5-9].

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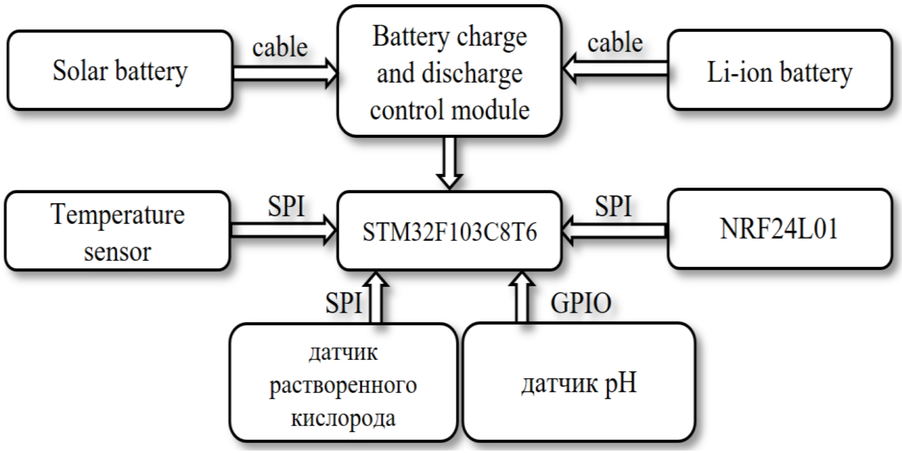

Figure 4. Block diagram of the hardware of the data collection terminal.

The remote online monitoring system displays all system parameters in real time. For the connection, the GPRS network is used, the connection to the NRF24L01 data collection terminals. To increase the radiation distance, a high gain module is added.

The data collection terminal is responsible for collecting water quality parameters and sending them to the base station of the transmission control center. STM32F103C8T6 is used as the main controller, and the terminal is equipped with temperature sensor, DO sensor and pH sensor. Data transmission is carried out using the NRF24L01 wireless transceiver module. The terminal uses a combination of solar panels and lithium batteries to supply power, and solar cells are used to power the system and power the lithium batteries during the day, and are charged and powered by the lithium batteries at night. The main function of a water quality monitoring system is to provide monitoring and control of water quality. According to the different water quality requirements and parameters in different growth stages, users adjust the water quality parameters according to the actual situation, so that the water quality can reach the most suitable growth state. Precise adjustment of water quality parameters is achieved using a PID controller that adjusts the parameters using an advanced particle swarm optimization algorithm. The system collects various water quality parameters and then compares them with user-specified parameters to determine if an adjustment is needed. The acquisition of water quality parameters introduces a digital filtering algorithm to eliminate sampling interference, and Fig. 5 shows the intelligent structure of the controller [10-12].

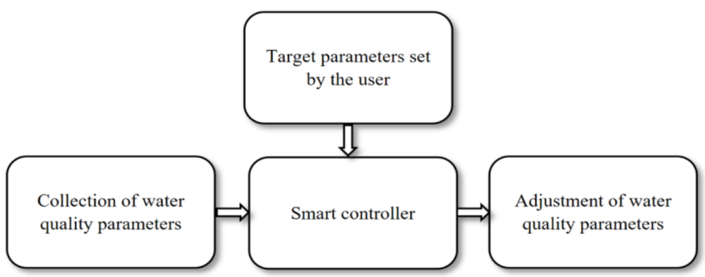

Figure 5. The structure of an intelligent controller.

Development of an algorithm for filtering data collection. Due to the difficult working environment of wastewater treatment, the measurement and transmission of temperature, pH and DO data are subject to various interferences, and unstable power supply and frequency interference will also affect the accuracy and reliability of the control system, resulting in inaccurate post-adjustment and control. To ensure the stable operation of the system and improve the accuracy and reliability of the system regulation during data collection, a filtering algorithm is added. Given that parameters such as temperature, pH, and DO change slowly during the measurement, interference is eliminated using clipping filtering and window length moving average filtering algorithms. Mathematical expression for the limit filtering algorithm:

$$X_{(K)}=\begin{Bmatrix} Y_{(K)}; Y_K - Y_{(K-1)} \leq A \\ Y_{(K)};\ Y_{(K)} - Y_{(K-1)} > A \end{Bmatrix} \tag{1}$$

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where: $X_{(K)}$ K value, $Y_{(K-1)}$- system K measurement, $Y_{(K-1)}$ - first Difference between system K-1 measurements and A-2 measurements.

In practical application, the determinant of the performance of the bandpass filter is the range of values of the empirical difference A, which can be obtained in accordance with the experience of observation and the actual analysis of measurements.

The flow of the moving average filtering algorithm is as follows: first determine a sequence of length n, load the continuous value of n-sample into a certain sequence, and the sequence value is $N = \{a_1, a_2, \dots, a_n\}$ averaging n data in this series gives the filter value K C_k.

$$C_{(K)} = \frac{1}{N}\sum_{i=1}^{N} a_n \quad (2)$$

Drop a_n, move a_n in a_{n-1} one bit high, put the value of the next encoder transform in a_1, and get a new sequence. The data in the table is again averaged to obtain the filter value of the K+1 the C_{k+1}.

Take data collection from temperature sensors as an example. The temperature in the water is 24°C during the test, and the output waveform after processing the filtered wave is shown in Fig. 6, when the temperature is not filtered and after adding a digital filter. It can be seen that the temperature data collected by the unused filter is relatively large, and the results after adding the filter are basically free of interference, and the experimental results prove that the developed digital filter has an excellent effect [13-16].

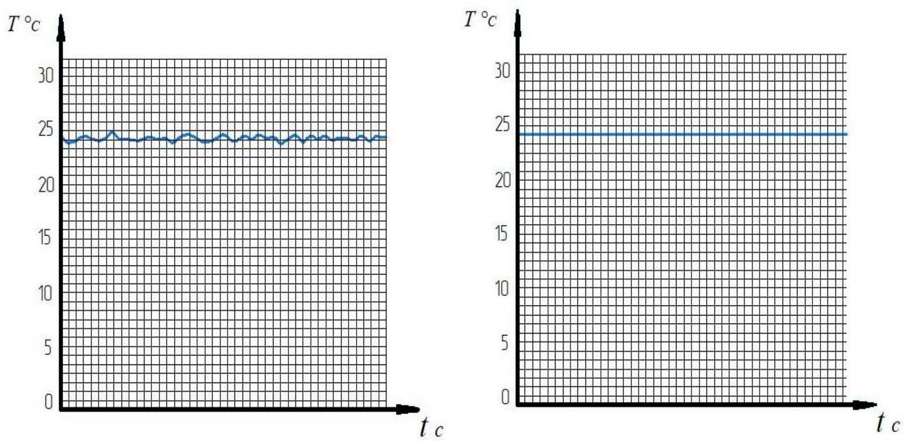

Figure 6. Temperature measurement output curve with digital filter

IMPROVED PID CONTROLLER FOR THE PARTICLE SWARM ALGORITHM

The control system must realize the regulation and control of water temperature, pH and DO, and the system uses PID controller to adjust and control each parameter of water quality, and uses advanced particle swarm algorithm to adjust and control 3 parameters PID, K_P, K_1 and K_D Optimized and monitored online to improve control Figure 6 digital filter temperature measurement output curve Machine performance and reliability The mathematical form of the particle swarm optimization algorithm is as follows PSO:

$$V_i = \omega \times V_i + C_1 \times Rand\ (0,1) \times \left(P_{best_i} - X_i\right) + C_2 \times Rand\ (0,1) \times (G_{best_i} - X_i) \quad (3)$$

$$X_i = X_i + V_i \quad (4)$$

where, ω - coefficient of inertia; V_i - speed example; P_{best_i} is the current best position, G_{best_i} is the best position of the target as well as the optimal value in

P_{best}, Rand (0,1) is a random number between (0,1) and C_1 and C_2 are learning factors.

PSO develops along two parameters: P_{best} and G_{best}.

To prevent PSO from falling into local miniaturization and improve the ability to search for particles in other locations, the standard PSO algorithm has been improved by pre-determining a random variable δ belonging to a Gaussian distribution (0, 1) in the G_{best} parameter is recalculated later in the algorithm.

$$G_{besti} = G_{besti} \times (0{,}5\delta + 1) \quad (5)$$

defines a quadratic random search factor ε that extends the quadratic optimization from the original position when the new particle optimization position is not as good as the current position and equation (4) becomes:

$$X_{i+1} = X_i + \varepsilon \times V_{i+1} \quad (6)$$

$$\text{Где, } \varepsilon = Rand\ (0,1) + 0,5 \quad (7)$$

PID controller control mode t is as follows:

$$u(t) = K_p \left[e(t) + \frac{1}{T_1} \int_0^1 e(t)dt + T_D \frac{de(t)}{dt} \right] \quad (8)$$

where - e(t) is the value of the systematic deviation; $e(t) = r(t) - c(t)$; K_p - scaling factor; T_i is the integration time constant; T_D is the differential time constant.

Using improved PSO algorithm for K_P in PID controller K_I, K_D for online tuning. In order to test and improve the effect of tuning the PSO algorithm to the PID parameters, Simulink is used to create a simulation model for temperature control in MATLAB, simulation experiments are carried out. As can be seen from the simulation results (Fig. 7), the response speed and control accuracy of the PID controller parameterized by the improved PSO are better than those of traditional PID controllers and have better reliability.

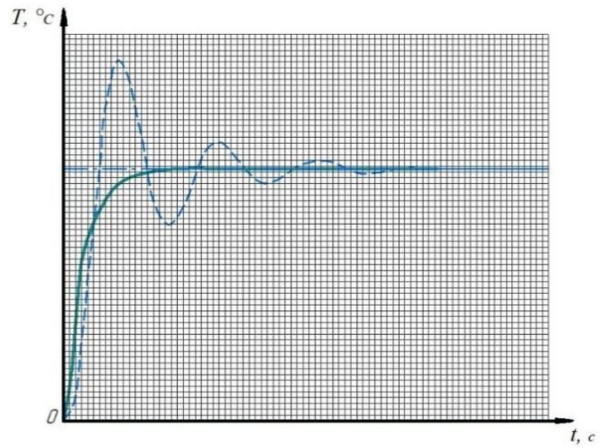

Figure 7. Improved PSO PID Controller Simulation Curve

(where, --- traditional PID controller, —— developed PID controller)

TESTS AND RESULTS

In order to check and test the reliability and stability of the designed system, a water treatment facility located in Andijan city was chosen as a test site, the area of which is 50 hectares, the water depth is 1 ~ 3 m. X_{02} to X_{13}. Actual tests have shown that the distributed network covers a radius of up to 650m, and the distance from the base station of the transmission control center to the remote monitoring center is 800m.

MEASUREMENT OF WATER QUALITY PARAMETERS

To check the accuracy of measuring the water quality parameters of the designed system, the corresponding parameters of the same water body are measured simultaneously by a standard device and the designed system, and two measurement results are compared. The table of test results shows: actual temperature 23.5°C, measured value 23.8°C; Actual pH 7.2, Measured value 7.2. Measured at 8.3 mg/L actual dissolved oxygen. The maximum measurement errors for temperature, pH, and dissolved oxygen are 2.1%, 1.3%, and 3.6%, respectively.

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To test the feasibility of the control method and the control accuracy of the system, 3 tests were carried out for temperature, pH and dissolved oxygen concentration. The test results for adjusting water quality parameters are shown in Table 1.

Table 1.

Control Options	№	Measuring parameters before tuning	Parameters according to the standard	Actual correction value Standard instrument measurement) / % of adjustment error		Adjustment time
Temperature, °C	1.	24	20	20,38	1,9	0,73
	2.	27	20	20,36	1,8	1,03
	3.	26,5	20	20,30	1,5	0,98
pH, (increase)	1.	5,4	7,4	7,56	2,2	0,36
	2.	5,8	7,4	7,59	2,6	0,30
	3.	5,9	7,4	7,56	2,1	0,28
pH, (decrease)	1.	9,4	7,7	7,88	2,4	0,37
	2.	9,2	7,4	7,57	2,3	0,47
	3.	9,7	7,4	7,57	2,3	0,55
DO, (mg/l)	1.	4,4	7,9	14	3,1	1,8
	2.	5,2	7,9	8,13	2,9	2,8
	3.	6,7	7,9	8,12	2,8	3,3

ANALYSIS OF RESULTS

Thanks to a comparative analysis of the measurement results of a standard instrument and the measurement results of the designed system, it can be seen that the error between them is very small, and the measurement accuracy meets all standards. After setting the WAN data transmission stability, the data collection terminal worked continuously for 72 hours, and the data transmission was stable. Analysis of the adjustment results can achieve the adjustment of temperature, pH and dissolved oxygen, and the maximum error of its adjustment is 1.9%, 2.6% and 3.1%, respectively. Adjusting the speed and accuracy can meet the needs of the wastewater treatment plant. The water quality results show that the system can adjust and control various water quality parameters, the adjustment speed is faster and more accurate than the manual adjustment method, the stability, accuracy and speed of the control system is better than the traditional manual adjustment method.

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