ABSTRACT

Dissertation for the degree of Doctor of Philosophy (PhD) in the specialty 6D071600 – "Instrument engineering" Bazarbai Lashin on the topic "Development of a multisensory system for monitoring water parameters"

Relevance of the research topic. Currently, the influence of anthropogenic and natural environmental factors on water resources is increasing. These factors have a direct impact on the physical, chemical and biological properties of reservoirs, leading to a decrease in water quality and disruption of ecosystem equilibrium. Such processes are becoming one of the urgent problems in the field of water safety and environmental protection.

Water is a key natural resource that plays a crucial role in maintaining the life of living organisms and biological balance. It is not only a source of life, but also one of the main environmental factors that ensure the stability and functional integrity of terrestrial and underground ecosystems.

In this regard, continuous and systematic monitoring of water quality is considered as one of the modern scientific and technical tasks. It is an important and strategically significant tool for ensuring environmental safety. However, water quality assessment is a complex and multifaceted process, fraught with a number of difficulties. The quality characteristics of water are constantly changing under the influence of various natural and anthropogenic factors. For an objective assessment of these changes and an accurate understanding of the dynamics of ecosystem processes, it is necessary to apply special analytical methods for complex analysis of water composition. Such methods make it possible to characterize the ecological state of water based on measurements of its physical (temperature, turbidity), chemical (pH, electrical conductivity, redox potential) and biological (organic substances, microflora) parameters.

Today, traditional laboratory methods based on the analysis of samples taken from reservoirs are widely used in monitoring water quality. These methods allow you to accurately determine many parameters and comply with regulatory requirements. However, they have a number of significant limitations: time delays in the control process, lack of continuous monitoring, difficulties in operational data processing, and spatial constraints. All this makes it difficult to objectively assess the state of the aquatic environment in real time and make timely decisions.

In addition, short-term laboratory methods do not always allow timely detection of dynamic changes in water quality. One of the reasons for this complexity is the lack of integrated systems capable of simultaneously and in real time measuring the five most important parameters of water: pH, turbidity, electrical conductivity, temperature and redox potential.

In this regard, there is a need to develop modern measurement systems based on Internet of Things (IoT) technologies capable of providing continuous and long-term monitoring in real time. The developed multi-sensor system allows simultaneous measurement of five key water quality indicators — temperature, turbidity, pH, redox

potential and electrical conductivity, providing comprehensive and reliable information about the state of the ecosystem. The system automatically transmits the collected data via the ESP32 microcontroller via Wi-Fi to the Blynk cloud platform, providing remote monitoring, visualization and operational data analysis.

The results of the correlation and regression analysis revealed statistically significant relationships between the main parameters of water quality. The analysis showed that temperature significantly affects other indicators, which justifies its use as a key predictor in building models for predicting water quality.

The average relative measurement error did not exceed 3%, which indicates the high reliability of the data obtained. At the significance level of $p < 0.05$, the correlation coefficients were determined in the range from $r = 0.3238$ to $r = 0.6999$, which indicates a statistically significant and non-random relationship between the physical and qualitative characteristics of water.

With increasing temperature, a decrease in the values of acidity, electrical conductivity, and turbidity was observed; the correlation coefficients for these bonds reached $r = -0.889$ to $– 0.998$. The influence of seasonal factors was also taken into account: temperature increases in different seasons were accompanied by an increase in redox potential, which is confirmed by autumn ($r = 0.940$) and spring ($r = 0.908$) values. The data obtained prove the existence of a close statistical relationship between the physical parameters of water and its qualitative indicators. This interdependence serves as an important scientific basis for modeling and forecasting the state of aquatic ecosystems. Taking into account the above, the development and implementation of a multisensory system for monitoring key water quality indicators in real time is an urgent and promising scientific and technical direction that meets modern requirements.

Thus, the creation of the proposed multisensory system for monitoring water indicators is a modern scientific and technical solution aimed at creating reliable means of integrated monitoring of water quality. This initiative is considered as a strategically significant scientific direction contributing to the modernization of the environmental monitoring infrastructure and rapid response to changes in the environment.

The degree of development of the research topic. The problem of water quality control is one of the priorities of modern scientific research in the field of ecology, hydrology and engineering monitoring systems. The issues of assessing the state of water resources are considered from the point of view of ensuring environmental safety, protecting public health and rational use of natural resources. In this regard, research on the development of methods and technical means for monitoring the parameters of the aquatic environment is widely represented in the scientific literature. In traditional approaches to water quality control, the main focus is on laboratory analysis methods that allow for high-precision determination of physico-chemical and biological parameters of water. Such methods are considered in detail in the works of domestic and foreign researchers involved in the analytical control of aquatic environments. However, the use of laboratory methods requires significant time and special equipment and does not always allow for rapid monitoring of changes in the parameters of the aquatic environment.

In recent years, considerable attention has been paid to the development of automated water quality monitoring systems based on the use of sensor technologies. Scientific publications cover various types of sensors for measuring parameters such as pH, temperature, electrical conductivity, turbidity, dissolved oxygen, and redox potential. The use of sensor technologies allows measurements to be carried out directly at the observation site and data to be obtained in real time.

A special place in modern research is occupied by multisensory monitoring systems that provide simultaneous measurement of several parameters of the aquatic environment. Such systems make it possible to comprehensively assess the state of water and identify the relationships between various quality indicators. Scientific papers also consider methods for processing measurement data, including statistical analysis, correlation studies, regression modeling, and the use of machine learning methods to predict changes in the aquatic environment.

At the same time, an analysis of existing solutions shows that many of the developed systems have high cost, complex architecture, and limited opportunities for scaling and integration into environmental monitoring systems. In addition, the issues of complex processing of data obtained from several sensors and improving the accuracy of assessing the state of the aquatic environment based on multisensory measurements remain insufficiently investigated. Thus, despite a significant amount of scientific research in the field of water quality monitoring, the task of developing effective, affordable and reliable multisensory systems for monitoring the parameters of the aquatic environment remains relevant. This determines the need for further research aimed at improving methods for measuring, processing and analyzing data obtained in multisensory water quality monitoring systems.

Object of the study is a multisensory measuring system based on the Internet of Things (IoT) technology, designed to monitor the physical and chemical parameters of aquatic ecosystems in real time.

The subject of this study is methods and means of multisensory monitoring of the parameters of the aquatic environment, as well as the processes of measurement, processing and analysis of data obtained during monitoring of the main indicators of water quality. The research examines the principles of constructing a multisensory system that provides simultaneous measurement of parameters such as temperature, acidity (pH), turbidity, electrical conductivity and redox potential, as well as methods of statistical processing and interpretation of the measurement data obtained for a comprehensive assessment of the state of the aquatic environment.

The purpose of the thesis is to develop a multisensory system based on physical methods of analytical control of water quality and designed to measure a number of quantitative indicators.

Research Objectives. Taking into account the set goal, the scientific tasks that need to be solved within the framework of the dissertation are highlighted.:

– critical analysis of methods used to measure five water quality indicators

(temperature, formazine turbidity, acidity, electrical conductivity, and redox potential);

– development of a multi-sensor system for water quality control, taking into account the selection of sensors designed to measure the physico-chemical parameters of water;

– designing the hardware and software architecture of a multi-sensor system;

– correlation and regression analysis of the relationships between water quality indicators based on the experimental data obtained;

– the study of the influence of temperature on water quality indicators and the construction of a linear regression model to describe them.

Research Methods. A multi-sensor measurement system based on Internet of Things (IoT) technology designed to monitor the physical and chemical parameters of aquatic ecosystems in real time.

Scientific Novelty:

1. For the first time, a new multisensory system based on physical sensors has been proposed that can simultaneously measure five key water quality indicators — temperature, acidity, formazine turbidity, electrical conductivity, and redox potential. Unlike previous systems that covered only three or four indicators, this system expands the possibilities of integrated water quality monitoring and allows overcoming the methodological limitations of previous approaches.

2. As a result of the study, a significant influence of water temperature on other indicators has been established. Experimental tests have shown that as the temperature increases, there is a decrease in acidity, electrical conductivity, and formazine turbidity, while the redox potential increases.

3. The study used more than 10,000 measurements, which ensured high statistical reliability and stability of the regression model. All the p-values of the coefficients of the models turned out to be below 0.05, which indicates the high predictive power of the results obtained and their statistical significance.

The theoretical significance of this work It consists in the development of scientific and methodological foundations for monitoring water quality based on multisensory technologies. The paper substantiates approaches to the construction of a multisensory system for monitoring the parameters of the aquatic environment and suggests methods for statistical processing of measurement data for a comprehensive assessment of the state of water.

Practical significance of this work:

Based on the results of experimental work, the developed multisensory system based on Internet of Things (IoT) technologies provides comprehensive water quality control in real time.;

– it is planned to widely implement research results in educational institutions, ecosystem research, industrial and municipal water supply facilities, as well as in agriculture and at the household level in order to monitor water quality;

– the developed methodological and technical solutions are adapted for use in the field of integrated water quality control and are relevant for effective use in the practical activities of specialized organizations and institutions;

– automatic transmission of the received data to a cloud server with subsequent visualization provides the possibility of remote control of the system and operational analysis;

– recommendations on the practical application of a multisensory water monitoring system.

Conclusions proposed for defense:

1. A multi-sensor system has been developed for continuous measurement of five main water quality indicators: temperature, acidity (pH), formazine turbidity, electrical conductivity and redox potential (ORP). The effectiveness and reliability of the developed system are confirmed by the results of experimental studies, which indicates its suitability for practical use.

2. The correlation and regression analysis revealed statistically significant relationships between water quality parameters. The results of the study showed that temperature has the greatest impact on other indicators, which gives reason to consider it as the main predictor when modeling water quality.

3. The relative measurement error did not exceed 3%, which confirms the reliability of the data obtained. Based on the measurements carried out, a statistically significant and non-random relationship has been established between the quality of water and its physical characteristics. The correlation coefficients ranged from $r = 0.3238$ to $r = 0.6999$ with a significance level of $p < 0.05$. This indicates a significant influence of physical parameters on the qualitative characteristics of the aquatic environment.

4. It was also found that an increase in temperature is accompanied by a decrease in acidity, electrical conductivity and turbidity, while the correlation coefficients range from $r = -0.889$ to $r = -0.998$. In addition, it has been experimentally confirmed that, taking into account seasonal factors, an increase in temperature leads to an increase in the correlation dependence in terms of redox potential, where the coefficients the correlations *were* $r = 0.940$ and $r = 0.908$.

The reliability of the results

The reliability of the research results is ensured by the use of modern measurement methods, statistical data processing and experimental research. The accuracy of the developed system is confirmed by the fact that the relative measurement error does not exceed 3%, and statistically significant dependencies between water quality parameters were established based on correlation and regression analysis at a significance level of $p < 0.05$.

Validation of the study results. Based on the results of the performed scientific research of the dissertation, 15 scientific papers were published, of which 3 articles, of which: 1 article was published in a journal indexed in the Scopus database (Q3, percentile 45), 2 articles were published in foreign publications included in international abstract

databases, 4 articles were published in a scientific publication recommended by The Committee for Control in the field of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 7 materials of international scientific and practical conferences, and also received 1 patent of the Republic of Kazakhstan for a utility model.