Development and experimental study of an intelligent water quality monitoring system based on the internet of things

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ABSTRACT

The goal of this work is to create an intelligent internet of things (IoT)-based water quality monitoring system that will effectively monitor and analyze water parameters, collect real-time data, and provide critical information for decision-making in water management and environmental issues. Provide data transfer over wireless networks such as Wi-Fi or Bluetooth. The scientific novelty of the project lies in the development of an innovative system that combines modern IoT technologies and machine learning methods to provide comprehensive and accurate water quality monitoring, which is a significant contribution to water management and environmental safety. Five sensors are connected to Arduino-Mega 2560, ESP-32-E in a discrete manner to determine water parameters. The extracted sensor data is transferred to a desktop application developed on the Blynk App platform and compared with World Health Organization (WHO) standard values. Based on the measurement results, the proposed system can successfully analyze water parameters using the fast forest binary classifier to determine whether the tested water sample is potable or not. An intuitive user interface has been created that will allow users to monitor and analyze water quality data in real time. Provide the ability to create graphs, charts, and reports for visual presentation of data.

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1. INTRODUCTION

The effect of water on any active creature is indescribable. With the rapid growth of the world's population, water management is becoming a major issue exclusively in the industrial, agricultural, and other sectors. Most people around the world lack drinking water. Every year, many people suffer from various serious diseases caused by water pollution. Research by World Health Organization (WHO) [1] has shown that approximately 5 million deaths occur solely due to drinking hazardous water. Research from the WHO shows that nearly 1.4 million child deaths could be prevented by providing drinking water. The fundamental goal of this project is to implement mental adjustment of water quality forecast on an internet of things (IoT) platform, which would help monitor all kinds of physiological characteristics of drinking water rather than relying on a manual process. Moreover, IoT is a system for connecting various devices and transmitting information throughout the system [2], [3].

Recently, several research works have been carried out to develop an intelligent system for identifying and monitoring water parameters. To monitor water quality and supply in real time, an embedded monitoring system based on sensor nodes is proposed in [4]. Their proposed architecture focuses on a low-cost, easy-to-implement electrochemical pipeline system, and the sensors used for this architecture are optical sensors. This system is suitable for categorizing large volumes of water, providing an approach to water buyers, water distributors, and water authorities. Pranata *et al*. [5] developed a middlemanless architectural framework for both publisher and subscriber for water quality monitoring. They analyzed measured data on temperature, pH, and dissolved oxygen in water samples and obtained an inverse relationship between them. To collect, monitor, and analyze water quality in remote areas, a remote sensing (RS) system based on IoTs was implemented for Fizi [6]. In the research manuscript [7], authors described smart IoT technology based on a real-time water quality monitoring system. Authors developed an industrial water quality monitoring system using four different sensors, such as turbidity, pH, temperature, and water level [8]. In research article [9], a system was developed in which temperature sensors were used to assess the nature of water. All information from the sensors is supplied outside the surveillance zone; the inspection zone is indicated using a ZigBee module connected to a PC. The research articles [4]-[11], present the results of research to develop a schema for collecting sensor data in close environments and industry areas. However, there were unresolved issues related to collecting data in lakes and rivers, where there are issues with the internet or connection to electricity.

In article [12], a design was developed and studied that regulates the composition of air and water using the Bluetooth wireless platform. It consists of various sensors such as temperature and humidity. In this system, water content is recorded by sensors and directly entered into the user's database via a Bluetooth device to monitor air and water quality. The APK file can be used to monitor the values of all sensor parameters from the system. The system used the same sensors, but instead of oxidation-reduction potential (ORP), the system had a thermal detector installed to estimate the water temperature. Kedia [13] investigated the prediction of water properties in rural areas where an economic concept based on cloud sensors is assumed. We looked at methods, sensors for determining water properties, introduced the concept of measuring water properties, and moved on to a thorough study of cloud-based sensor arrangements. However, it is naturally unwise to immediately improve the properties of water, the effective use of shocks and financial execution can promote the growth of water properties and its acceptance by every person. Dinh *et al.* [14] developed a system that evaluates water volume such as humidity, oxygen concentration, electrical conductivity, pH, minerals, and water level to monitor water quality. The widespread need for abbreviated deliberate testing systems in freshwater catchments, ephemeral, and coastal water bodies is exceptionally high around the world. In addition, they also work with instrumented procedure sensors and a coordinated electrometer combination supplied by Tyndall. Qiao and Song [15] proposed a design based on a transboundary web-based procedure for monitoring water properties. This system sends information from the sampling sensors to the forecasting system through general packet radio service (GPRS) data transmission, it shows the values of the object parameters, which can be accessed via the internet. A wireless sensor-based water property prediction scheme is proposed, which includes sensors such as turbidity, pH sensor, temperature, water level sensors, and CO^2 sensors. This sensor performs the entire service and is tested using special cloud remote devices [16]. As in the previous research articles, the authors focused on data collection and engineering approaches to data collection. However, they did not consider data analysis and forecasting of target values.

The concept of real-time measurement of water properties based on global system of mobile communications (GSM), a classical method for assessing the nature of water, is to physically accumulate samples and send them to an experimental center for research, but this policy is time-consuming and impractical [17]. Here we described a multi-parameter water quality testing system for the Bristol Floating Harbor that efficiently collected continuous water quality information with the highest repeatability and displayed continuous information on the Internet using wireless sensor network (WSN) technology. This article presents a collection of three different sensors such as chlorine (ORP), pH, and turbidity. Based on the sensor readings, it determines whether the water is safe to drink or not [18]. Fiber optic spectral environmental sensors are currently used to monitor the marine environment. It detects subtle changes in the level of water decomposition [19]. A WSN is used to monitor water quality. Remote sensor networks (WSNs) have achieved the usable value of water property by monitoring how the system will be able to purify the water, continuously improving the quality, and the residue reservation component independently extends the organization's operating interval [20]. The system can be used to determine the biophysical limits of water properties such as flow, temperature, pH, electrical conductivity, and rate of oxidation decline [21]. Continuous supply of water while developing a quality forecast that guarantees the safety of drinking water supply and its nature is gradually being implemented using IoT. Arduino-based water detection system technology with three sensors that affect volumetric water parameters such as pH, turbidity, and chlorine. The measured values are displayed on the LED monitor [22].

Independent systems for predicting water properties using biosensors that are installed in the stream for continuous prediction have been invented [23]. The intelligent water property prediction system enables the application of IoT and measurement of sensor values using RS technology to obtain clear values, but it is more expensive than the proposed system in this paper. In this proposed system, we implement the water property as in the proposed system using an Arduino board to search for the water property [24]. Coordination of various sensors with Arduino to determine the parameters of display additions in real time is discussed [25]-[29]. Water quality monitoring in the Pacific Ocean describes the non-hazardous provision of drinking water and real-time monitoring of water properties using various technologies such as XMPP, Raspberry PI, CoAP, and HTTP, and information can be found on the internet using distributed computing [30]. New technology trends are currently helping to automate the process of collecting and storing data. This suggests that it is advisable to conduct a study on edge and cloud technology.

Therefore, research devoted to developing this and similar technologies is highly relevant, as it addresses critical water quality monitoring and management challenges. The growing concerns over water pollution and the need for real-time monitoring systems to efficiently collect, analyze, and disseminate data highlight the importance of innovative solutions. The purpose of this research is to develop an intelligent water quality monitoring system using an IoTs platform. Four physical parameters: temperature, pH, conductivity, and turbidity of different water samples are measured using four special sensors equipped with Arduino-Mega 2560 and FireBeetleESP-32-E. The extracted sensor data is analyzed using a fast forest binary classifier.

2. METHOD

The proposed design of an intelligent water quality monitoring system based on the IoTs is capable of reading information from water samples with sensors using a microcontroller and analyzing them with the support of a machine learning algorithm to predict the properties of water. The proposed block diagram of the system in Figure 1 consists of 5 different sensors connected to a controller to measure four essential physical parameters (pH, temperature, conductivity, turbidity, and water redox potential) of water samples. The SEN0161 pH sensor is used to measure the acidity or alkalinity of each solution on a logarithmic scale. The DFR0198 digital temperature sensor guarantees clear information in the range from -55 to 125 ºC. The DFR0300 analog sensor is used to measure the electrical conductivity of a water sample. The recommended reading range for this sensor is 1 to 15 ms/cm at temperatures from 0 to 40°C. The SEN0189 turbidity sensor is used in the design to detect the presence of suspended particles with a light substrate. An ORP meter is a device that measures the redox potential of liquids. Compact, reliable, and accurate, the device looks like a mobile phone with a sensor. After lowering the sensor into the liquid for a minute, you will see an ORP indicator on the electronic screen. The extracted data from the sensor data is accessed by the Arduino-Mega 2560 and ESP-32-E controller and passes it to the developed desktop application.

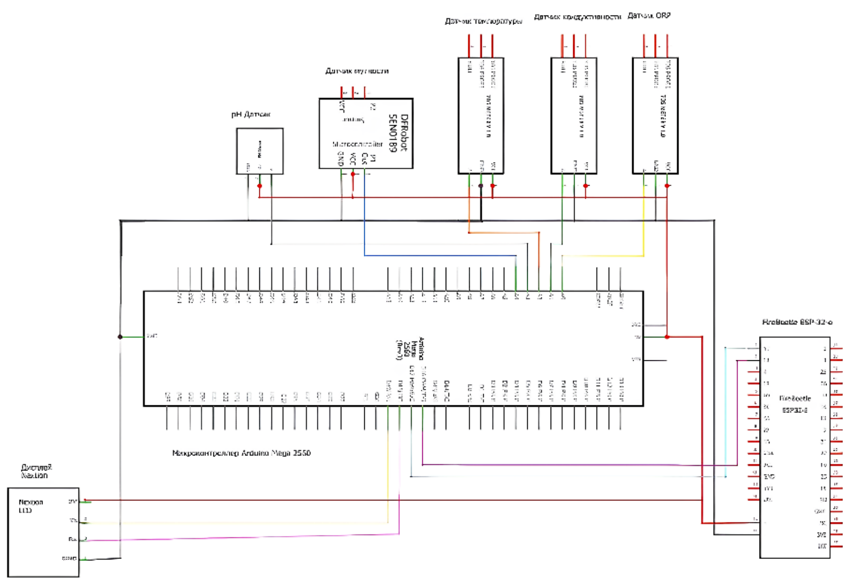

Figure 1. Schematic diagram of the hardware of an IoT-based water quality monitoring system

A machine learning algorithm is implemented on the server side to model water properties based on measured data. Rudakov *et al.* [31] compare deep learning architectures for time series analysis in different industry areas. These researches highlights the potential of deep learning approaches in improving the reliability and efficiency of monitoring systems in industrial applications. Since the design predicts whether the water sample being tested is potable or undrinkable, the fast forest binary classifier algorithm is used. 20 different water samples were taken from nearby water pipes, filters, soft drinks, and other sources. The reliability of modeling the system under study was compared with experimental data. Figure 1 presents the schematic diagram of the proposed IoT-based water quality monitoring system, illustrating the integration of various sensors with an Arduino-Mega 2560 and ESP-32-E microcontroller. The diagram shows how the sensors are connected to measure key water parameters, including pH, temperature, conductivity, turbidity, and ORP.

Figure 2 shows a schematic diagram of the hardware version of the proposed system. With the exception of the temperature sensor, the other three sensors are analog type. Each sensor has three wires of different colors such as red, dark, and others. Here, red wires are needed for 5 V power, dark wires are needed for grounding, and others are used for data evaluation. A breadboard device is used to gradually create common ground and power supply points. Next, the common ground section is connected to the ground of the Arduino-Mega 2560, ESP-32-E, and the same process is repeated for the power supply. The analog detectors are connected to the analog terminals and the digital sensor is connected to the digital terminal of the controller. The block diagram of the controller and sensors workflow is shown in Figure 3. It outlines the flow of data from the sensors to the microcontroller, and then to the display and cloud storage, enabling real-time monitoring and analysis of water quality parameters.

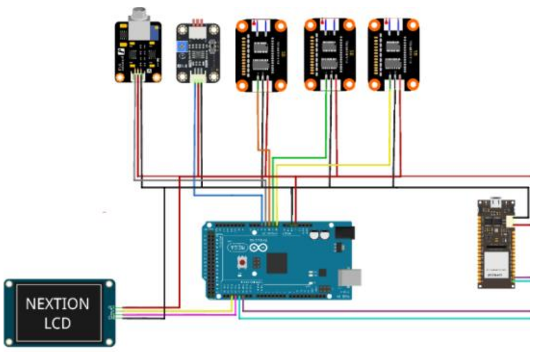

Figure 2. Schematic diagram of the hardware version of the proposed system

For the proposed system, the extracted sensor data is analyzed accordingly to predict the accuracy of the system. In Figure 4, there is the code of binary classify, the random forest binary classifier [9] was implemented in which various water samples such as salt, dirt, wastewater, tap water, soft drinks, and drinking tap water are selected to process the dataset. The average combination of many small and weak decision trees in a fast forest regression model produces a strong learner. The algorithm works as follows: for each tree in the forest, a bootstrap sample is selected from Z. In this situation, Z is the bootstrap of i. This decision tree method is modified by the decision tree learning algorithm. A random subset of objects $a \leq X$, where X denotes a set of objects. Here a is much smaller than X. Fast forest algorithms return the value R, which is the set of the train model. When the feature set is narrowed, the process of learning the feature set is greatly accelerated.

The conceptual schema is presented in Figure 5. The principle of operation of this system begins with supplying a 220 V current source through a switch to the power supply, which converts the current from AC to DC and reduces the voltage from 220 to 12 and 5 V. 5 V is supplied to the Arduino Mega 2560 microcontroller and FireBeetle ESP-32- E. The 12 V voltage is supplied to the cooler, which cools the entire system.

From the microcontroller, voltage is supplied to the Nextion sensors and display, presented in Figure 6. In sensors, measuring the potentials at the ends of the electrodes sends a signal to the microcontroller. The controller will decrypt the data and send it to the Nextion display and the fire beetle ESP-32-e controller. The next display shows the data in the interface. Fire Beetle ESP-32-e connects to a Wi-Fi network and transfers data to cloud storage. With the Blynk Iot app, we can see the data in the browser and mobile application.

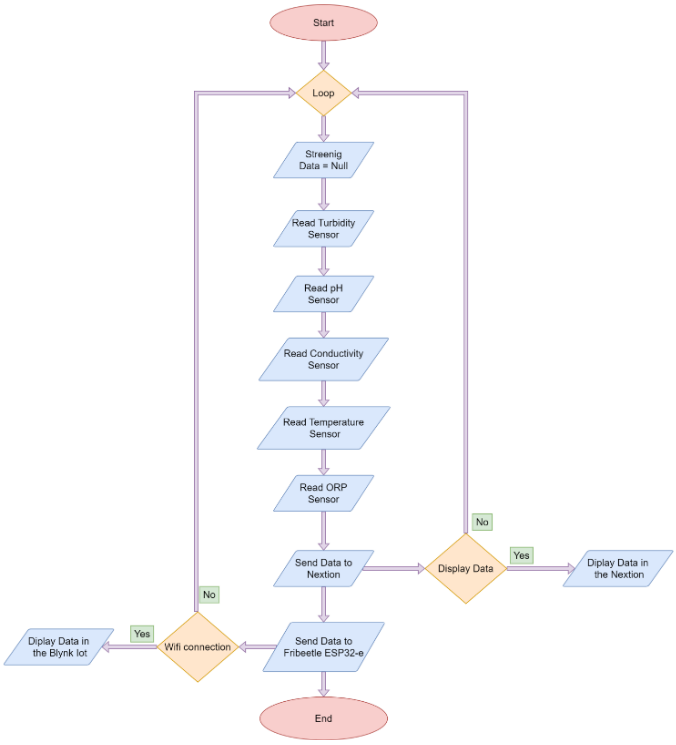

Figure 3. Block diagram of the equipment operation procedure

Figure 4. Binary algorithm for this system

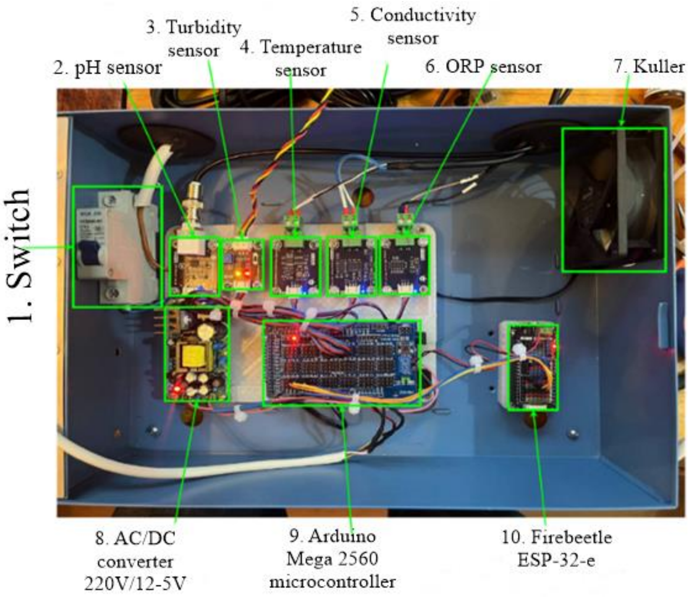

Figure 5. Complete experimental setup of the developed system

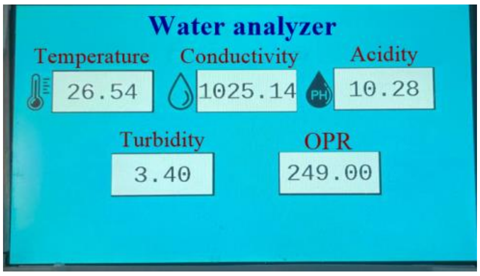

Figure 6. Management controller interface

3. RESULTS AND DISCUSSION

3.1. Numerical result from pinn

Fifty samples of water are taken from different sources and tested to measure such parameters as pH, temperature, electrical conductivity, turbidity, and ORP of water for each sample. These water sources are divided into three categories: natural, untreated, and drinking water sources. Figures 7-10 show the extracted values corresponding to the four physical parameters for one water sample.

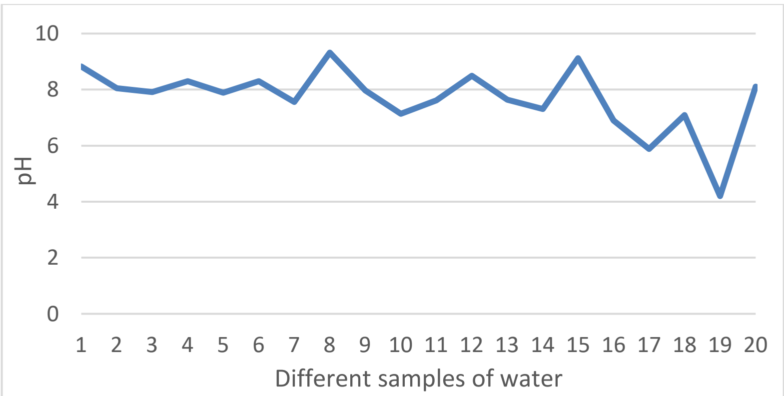

Figure 7. Parameterization of the Sobra by data pH

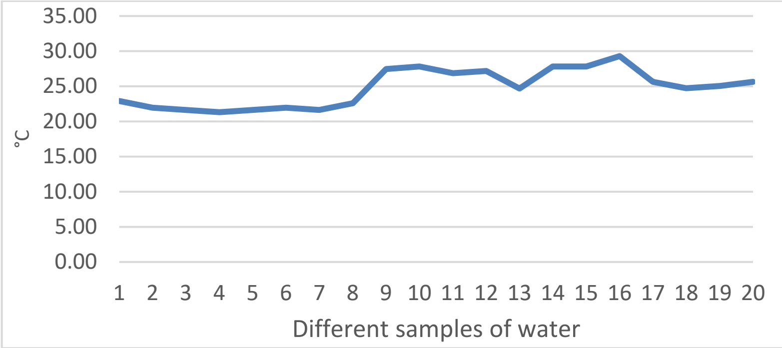

Figure 8. Collected temperature data

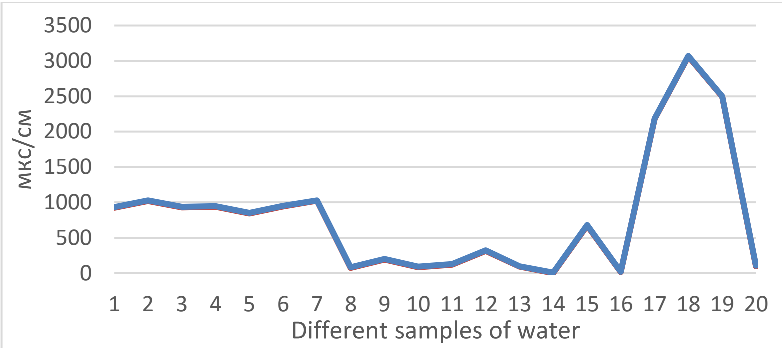

Figure 9. Conductivity data collected this way

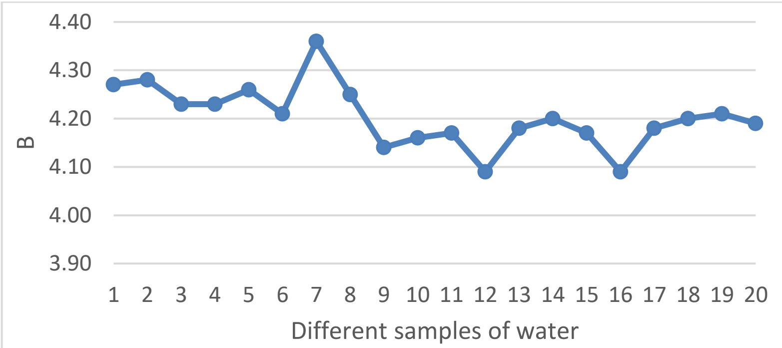

Figure 10. Turbidity data collected this year

Table 1 presents an overview of each physical parameter for 60 samples (83% of the data were used for training and 17% as test data), divided into three categories of water sources, and the percentage of concentrations that are not included in the standard values of WHO [10] is shown. General recommendations on the level of pH of drinking water, recommended by WHO, are about 6.5-8.5. It can be seen from the table that about 80% of the tested water samples exceed the recommended pH range, being alkaline in nature, which indicates the presence of carbonates and limestone in the water samples. As a result, the excess content of alkali in the human body can cause skin irritation, gastrointestinal, and metabolic alkalosis. Turbidity is a serious problem from the point of view of analyzing the properties of water and the presence of microorganisms. According to the manual, the corresponding turbidity level should be below 5 nephelometric turbidity unit (NTU). The results demonstrate a high turbidity value for impure water compared to natural water samples. Electrical conductivity plays an important role when measuring water properties or pollution levels [32]. The conductivity of drinking water ranges from 0.3 to 0.8 microseconds/cm. According to the table, more than 70% of the electrical conductivity of the tested sample exceeds the standard value of WHO.

Table 1. Time comparison of the PINN method and numerical simulation

Parameters	Coordinates	Location	Acidity	Conductivity	Turbidity	ORP	Temperature
1	41°15'08.06 N 67°57'45.88E	https://goo.gl/maps/8d3zCsv6kL5xfYco9	8.82	922.57	4.27	360.45	22.89
2	41°00'41.10 N 68°09'35.2 E	https://goo.gl/maps/p928bdwmBSuCVtLu6	8.05	1017.96	4.28	381.45	21.95
3	41°13'40.92 N 68°18'15.98 E	https://goo.gl/maps/tGM5GtSYdQHsmoMe7	7.91	928.55	4.23	351.00	21.65
4	42°13'37.45 N 68°18'11.51 E	https://goo.gl/maps/SpKqBNNDVtzmrfz18	8.30	938.08	4.23	337.58	21.32
5	41°15'04.97 N 67°57'49.32 E	https://goo.gl/maps/GaW4cniLx1j2FG2K9	7.89	842.63	4.26	395.12	21.64
6	42°13'41.92 N 68°18'16.79 E	https://goo.gl/maps/6xHCQErStwiX6b148	8.30	941.54	4.21	363.00	21.95
7	41°00'38.88 N 68°09'54.22 E	https://goo.gl/maps/KJdyLQ7ytN9yhiFcA	7.56	1021.39	4.36	371.76	21.64
8	43°08'26.9 N 77°00'31.2 E	https://goo.gl/maps/d5jRL4h2ZkrBm56N6	9.32	72.24	4.25	376.45	22.58
9	42°56'07.3 N 72°45'54.3 E	https://goo.gl/maps/QwhQAPNAVCuK9r5z9	7.97	191.86	4.14	258.00	27.48
10	43°18'45.2 N 76°51'14.2 E	https://goo.gl/maps/jFLSTHwYuta8qrXS9	7.14	84.31	4.16	322.00	27.80
11	Asu water	https://www.instagram.com/asu_water/	8.49	312.49	4.09	268.00	27.17
12	Turan water	https://www.instagram.com/asu_water/	7.64	89.50	4.18	307.00	24.70
13	Tassay water	https://www.tassay.ru/	7.31	0.00	4.20	322.00	27.80
14	Samal water	https://samal.kz/	9.12	669.22	4.17	249.00	27.80
15	Asem ay	https://www.instagram.com/asemai_water.kz/	6.90	13.47	4.09	385.51	29.30
16	Living water	https://alivewater.kz/	5.88	2180.37	4.18	366.00	25.66
17	Burabay	https://www.burabay-qulager.com/	7.09	3063.00	4.20	317.00	24.72
18	Birjomi	https://live-legend.borjomi.com/ru	4.20	2495.18	4.21	312.00	25.03
19	Nabeglavi	https://www.instagram.com/nabeghlavi.kz/	8.11	96.89	4.19	302.00	25.66
20	Satpaev 22B	https://goo.gl/maps/kbj33C5RYHFmhDss9					

3.2. User interface and monitoring of devices related to the Blynk compatible platform

Our findings indicate in Figures 7-11 that the Arduino-based schema successfully collects data. The system's use of multiple sensors ensures accurate measurement of key water parameters, and the integration with the fast forest binary classifier enhances its ability to determine water potability. This robust performance highlights its potential for broader environmental monitoring and water management applications. Another step of the system is to store collected data in the cloud, which helps monitor water quality in real time. For this point, we considered the Blynk IoTs platform [33].

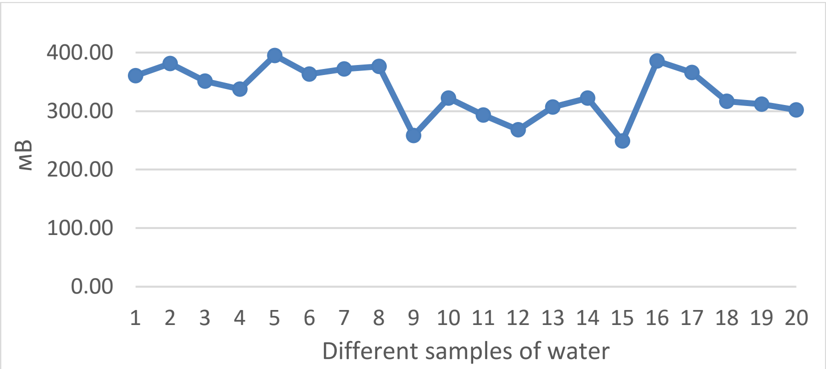

Figure 11. Collected data on the ORP of water

Blynk IoT is an IoTs development platform that allows you to create IoT projects and manage them using an easy-to-use mobile application and cloud service [33], Figure 12 presents an example of the user interface of the Blyk application. As part of the Blynk IoT platform, it is possible to use a database to store and manage data collected from IoT devices. The database in the Blynk Iot platform allows you to save and systematize data collected from IoTs devices and provides access to them from the Blynk application or other integrated services. It provides a flexible structure for storing and retrieving data, as well as functions for performing various data operations, such as adding, updating, deleting, and querying.

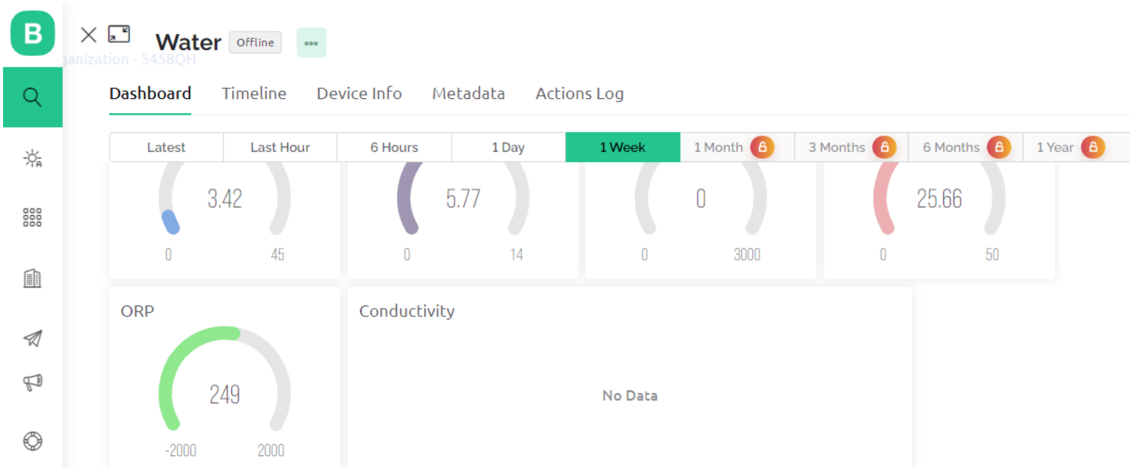

Figure 12. Blynk IoTs platform and browser interface

The main functions and capabilities of the database in the Blynk IoT platform include:

– Data storage: the data base allows you to store data received from IoTs devices in a structured form. This may include information about sensors, device status, logging logs, and other parameters that may be useful for analysis and decision-making.
– Data organization and name management: the database provides an opportunity to organize data and manage names in a convenient format. You can create different tables or collections to store different types of data and use different fields and indexes to simplify data searching and filtering.
– Data retrieval and requests: the database allows you to perform requests to retrieve specific data based on specified conditions. You can use filters, sorting and other operations to get the desired results. This allows you to efficiently process and analyze large volumes of data.
– Integration with other services: the database on the Blynk Iot platform is integrated with other services and tools for data processing and analysis. You can use data visualization, graphing, notification creation, and other functions for convenient display and use of data.

In general, the database on the Blynk Iot platform provides convenient and efficient storage, management and use of data collected from IoTs devices. It provides flexible opportunities for data organization, execution of requests and integration with other services, which allows you to effectively work with data and make decisions based on it. Blynk IoT Mobile is a mobile application designed for IoTs development and management, Figure 13 presents an example of the user interface of the Blyk mobile application. It provides a convenient interface for creating user interfaces and device monitoring related to the Blynk compatible platform.

The main functions and features of the Blynk IoT mobile application:

– User interface creation: Blynk allows users to create user interfaces that display on a mobile device. Users can add widgets such as buttons, indicators, graphics, and other elements to monitor and display data from connected devices.
– Connecting to IoTs devices: the Blynk application supports integration with a wide range of IoTs devices, such as Arduino, Raspberry Pi, ESP8266, particle, and other platforms. Users can easily connect and manage their devices with Blynk.
– Remote control: Blynk allows users to remotely control their devices and IoTs via the internet. Users can turn devices on and off, configure settings, send commands, and receive feedback from connected devices.
– Visualization of data: Blynk provides an opportunity to visualize data from connected devices in the form of graphs, charts, indicators, and other elements of the interface. Users can monitor and analyze data in real time.
– Notifications and alerts: Blynk supports sending notifications and alerts to mobile devices. Users can set conditions and events that will trigger them to receive notifications, such as when the device status changes or when a certain parameter value is reached.
– Cloud storage: the Blynk app offers cloud storage where users can save and synchronize their projects and data. It provides access to projects and devices from any device, and also provides backup and recovery of data.

Figure 13. Mobile application Blynk IoT mobile and data changes for one month in stationary mode

The Blynk IoT mobile application has a simple and intuitive interface that allows users to create and manage their IoT projects without the need for deep programming knowledge. This facilitates the process of development and integration of IoTs devices and provides an opportunity to create innovative solutions for automation and control of various systems. The current limitation of the research is that in the first stage of research, we focused on a narrow set of water quality parameters, omitting others like dissolved oxygen or microbial contamination. Another point of limitation is to rely heavily on stable internet connectivity, which may not be available in remote areas, affecting its real-time functionality. The system's accuracy is contingent on regular sensor calibration and maintenance, which could be challenging over time.

The research results demonstrate that the developed IoT-based water quality monitoring system successfully met its objective of real-time, accurate analysis of key water parameters, confirming the hypothesis that such a system can reliably classify water as potable or non-potable using machine learning techniques. The fast forest binary classifier proved effective in this classification, aligning with the study's goal of integrating IoT and machine learning for environmental monitoring. Compared to other studies, this system stands out for its use of a combination of multiple sensors and a machine learning model, which provided a higher level of accuracy and real-time functionality. The results also highlighted the system's potential for broader application in water management, offering a more comprehensive approach than many previous studies.

4. CONCLUSION

The final goal of this work is to monitor the quality of water samples by developing an intelligent device for monitoring water quality, implemented on the IoTs platform, which can focus on four specific physical parameters: temperature, pH, turbidity, and electrical conductivity of water, as well as redox potential of water for analysis extracted value from these parameters using a suitable approach to machine learning. All types of water samples are tested using sensors Arduino-Mega 2560, ESP-32-E, and their values are collected for various indicators. Binomial classifier fast forest determines the best performance through careful analysis to confirm the accuracy and performance of the system in predicting water quality. The system has proven its importance, guaranteeing accurate work in determining the quality of water based on physical parameters. Thanks to the improved IoTs technology for determining the chemical parameters of water, in the near future this design can be implemented as a solution for real-time water monitoring.

The results indicate that the system can provide accurate and timely information, which is essential for ensuring water safety and addressing environmental challenges related to water quality. Compared to other systems, this solution integrates multiple sensors and a machine learning model uniquely, contributing to the field of environmental monitoring by providing a more comprehensive and efficient approach. In further research, we focused on extending sensors to monitor another chemical parameter of water. Furthermore, we would like to incorporate RS to find a correlation between sensor values and satellite images.

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