Journal of Edge Computing, **2023**, 2(2), pp. 163-174 https://doi.org/10.55056/jec.633

Edge computing in environmental science: automated intelligent robotic platform for water quality assessment

Andrii G. Tkachuk[1], *Mariia S.* Hrynevych[1], *Tetiana A.* Vakaliuk[1,2,3,4], *Oksana A.* Chernysh[1] and *Mykhailo G.* Medvediev[5]

[1]*Zhytomyr Polytechnic State University, 103 Chudnivsyka Str., Zhytomyr, 10005, Ukraine*
[2]*Institute for Digitalisation of Education of the NAES of Ukraine, 9 M. Berlynskoho Str., Kyiv, 04060, Ukraine*
[3]*Kryvyi Rih State Pedagogical University, 54 Gagarin Ave., Kryvyi Rih, 50086, Ukraine*
[4]*Academy of Cognitive and Natural Sciences, Ukrainian Branch, 54 Gagarin Ave., Kryvyi Rih, 50086, Ukraine*
[5]*ADA University, School of Information Technologies and Engineering, 61 Ahmadbay Agha-Oglu Str., Baku, AZ1008, Azerbaijan*

Abstract. This paper introduces a novel intelligent robotic platform designed to expedite and enhance the process of water quality assessment and bottom relief analysis in reservoirs. The platform, equipped with an array of sensors and actuators, is capable of conducting comprehensive studies over larger areas of the reservoir, thereby overcoming the limitations of traditional water analysis methods. The platform's advanced design includes a control board, servo motors, a brushless motor, a radio module, a GPS module, and a motor speed controller, all housed within a robust casing. The paper presents a functional diagram of the platform and discusses the results of a system study conducted on a reservoir. The study aimed to verify the system's operation, evaluate the effectiveness of the research conducted, and calibrate water quality sensors. The platform utilizes an ultrasonic sensor for depth measurement and sensors for water acidity and temperature. The results of the monitoring system experiments led to the creation of a detailed map of the reservoir's bottom area and provided valuable insights into water quality[1].

Keywords: edge computing, environmental science, intelligent robotic platform, water quality assessment, reservoir bottom topography, ultrasonic sensor, water acidity, water temperature, GPS module, motor speed controller

1. Introduction

As we grapple with the modern realities of rapidly increasing consumption and waste generation, the potential of new digital technologies to counterbalance these changes becomes a pressing

[1]This article is an extended version of the paper presented at the Workshop for Young Scientists in Computer Science & Software Engineering [14]

andru tkachuk@ukr.net (A. G. Tkachuk); mariia.skyless@gmail.com (M. S. Hrynevych); tetianavakaliuk@gmail.com (T. A. Vakaliuk); chernyshoxana@gmail.com (O. A. Chernysh); miserablewisdom@ukr.net (M. G. Medvediev)
https://ztu.edu.ua/teacher/285.html (A. G. Tkachuk); https://ztu.edu.ua/teacher/5.html (M. S. Hrynevych); https://acnsci.org/vakaliuk/ (T. A. Vakaliuk); https://ztu.edu.ua/teacher/187.html?type=dean (O. A. Chernysh)
0000-0003-2466-6299 (A. G. Tkachuk); 0000-0001-9183-5211 (M. S. Hrynevych); 0000-0001-6825-4697 (T. A. Vakaliuk); 0000-0002-2010-200X (O. A. Chernysh); 0000-0002-3884-1118 (M. G. Medvediev)

question. The need for innovative solutions to combat climate change and safeguard planetary well-being is evident.

Water pollution, defined as the adverse alteration in the physical, chemical, and bacteriological attributes of water due to an excess of inorganic, organic, radioactive, or thermal substances, poses a significant barrier to the use of water resources for drinking and economic activities.

While natural water bodies like oceans, rivers, and lakes have inherent self-purification abilities, an overload of pollutants can lead to irreversible damage, emphasizing the critical role of pollutant quantity management.

The presence of excessive chemicals, bacteria, and other microorganisms can lead to severe water pollution. These pollutants, which include chemical, organic, and mineral substances, form colloidal solutions and suspensions. Their chemical composition is influenced by natural factors such as the decomposition of substances in soil and rocks, the life cycle of aquatic organisms, and human-induced factors.

To address these challenges, we propose an intelligent robotic platform capable of remotely analyzing water in reservoirs. This platform measures water acidity, temperature, and depth. Upon detecting increased acidity or water pollution, it enables the collection of a water sample from a specific reservoir area for detailed analysis in a terrestrial laboratory. Equipped with real-time sensor readings and executive mechanisms, the platform can identify pollution sources and mark the exact location by deploying a beacon at the point of highest pollution concentration, facilitating further investigation into the nature and level of pollution.

Furthermore, this platform serves as an invaluable tool for training skilled economists, promoting environmental consciousness, and encouraging the application of knowledge to behavioral models. This integration of edge computing in environmental science exemplifies the potential of digital technologies in addressing modern environmental challenges.

2. Theoretical background

The escalating issue of water pollution necessitates innovative solutions. While "mobile" laboratories enable field research, they entail a lengthy process requiring meticulous preparation and initial water sampling.

The system presented herein is unique, with no exact counterparts currently available.

Automated surface platforms, both fully autonomous and controlled, have been explored in [2, 4, 5, 9–11]. These platforms are designed for extreme conditions, facilitating oceanic research or cargo transportation along predetermined routes.

Sea Machines [12] underscores an autonomous self-piloting system that enables remote vessel control, sensor data acquisition, and comprehensive vessel state monitoring.

Li et al. [8] proposes a spectral processing method for analyzing water sample reflectivity and employs machine learning techniques to estimate water quality parameters.

The objective of this investigation is to develop an intelligent robotic platform for conducting geodetic and environmental research. This platform is designed to be user-friendly, mobile, and efficient compared to similar systems. It facilitates rapid water sample collection for precise and detailed laboratory analysis. Additionally, it contributes to a practical experiment to evaluate the effectiveness of the robotic platform and the accuracy of the system.

Bezvesilna et al. [1], Koval' [7] discuss contemporary sensors for measuring acceleration and gravity anomalies but do not address their applicability in the design of intelligent robotic platforms.

Various control mechanisms for intelligent robotic platforms are suggested in [3, 13]. These include a fuzzy neural network and a Kalman filter for mobile robot control, a stabilization algorithm with a closed-loop control system incorporating an inertial measuring unit as a feedback sensor, and a control system for calculating engine angles to maintain stability on inclined surfaces.

3. Results

3.1. Intelligent robotic platform architecture

Researchers at Zhytomyr Polytechnic State University have engineered an intelligent robotic platform for environmental research. This system, designed with cost-effectiveness and mobility in mind, outperforms its known counterparts. The robotic platform's design (figure 1) comprises several key components: a body; a control unit that includes a Raspberry Pi mini-computer, a radio module, water turbidity sensor; temperature and acidity sensor; gas sensor; gyroscope and GPS; a brushless motor with a cooling jacket and a motor regulator; a battery; servomotors; the steering wheel. Also, a camera is installed on the mobile platform, video and sound from which are transmitted to the video receiver via two channels. This was done in order to improve the control of the platform and to be able to clearly see the state of the reservoir and the presence of debris on it.

Further, all these data are sent via the telemetry module to the operator's Raspberry Pi mini-computer, where they are recorded and can be further processed.

The platform's equipment is powered by a Turnigy Li-Po 11.21 1600mAh battery, which ensures long-term operation and provides the necessary power supply voltage for the system's correct functioning. Raspberry Pi mini-computer serves as the control device due to its compact size and ability to handle all tasks set in this project. The radio module is used for remote data transmission and platform control, ensuring quality signal reception and transmission up to a distance of 1 kilometer. The platform employs various sensors to gather environmental data: a water acidity sensor, water turbidity sensor, gas sensor for measuring the level of harmful gases on the water surface, a digital sensor for measuring water temperature, and a camera (video transmitter, video receiver) for detecting floating obstacles. Data from the sensors through the ADC shield is received and processed by the Raspberry Pi mini-computer. The GPS module, gyroscope, camera and the active antenna are used to determine the system's exact location and link the received data to precise coordinates. The executive mechanisms are servomotors, which are necessary for ensuring the swimming platform's movement in the required direction, and unloading the cargo placed in two cargo compartments on top of the platform.

3.2. Control panel

We developed the control panel for the platform by modernizing the existing panel, the structural diagram of which you can see below.

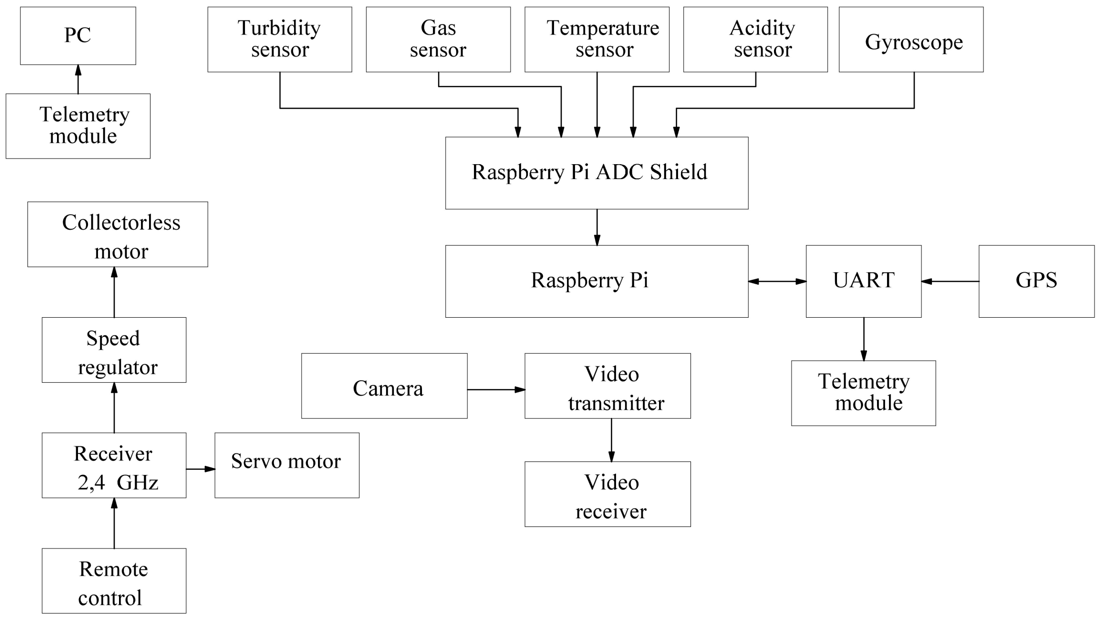

Figure 1: Structural elements of the automated robotic platform.

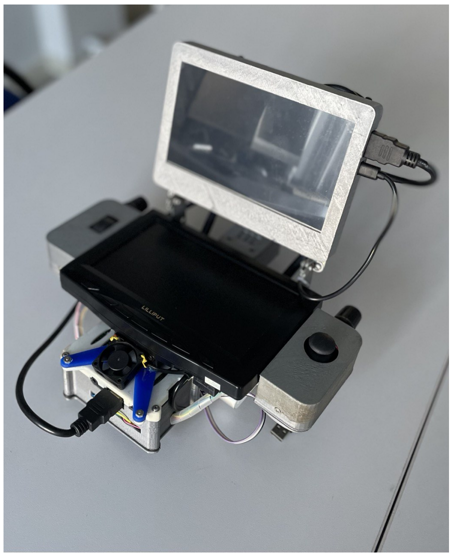

Figure 2: Remote control panel.

The platform's operations are managed by the Raspberry Pi mini-computer, which is responsible for data processing. It also functions as a control device, processing data from the GPS module and storing it on a flash drive.

Remote control of the platform is achieved using joysticks, while buttons are utilized to operate the cargo compartments and activate the water sampling system. The system's status is indicated via LEDs.

All data through the telemetry module are sent to the control panel (figure 2), where they are recorded and can be further processed.

3.3. System operation algorithms

The operation of the robotic intelligent platform necessitates the synchronized functioning of the swimming platform and the remote control, which involves data transmission and reception. Initially, as per the system's algorithm (figure 3), the controller ports are configured and the input data is reset. In this context, the robotic intelligent platform, acting as the data exchange initiator, is considered the transmitter. A connection request is then broadcasted to the control panel. If no response is received, the connection request is cyclically rebroadcasted. Upon establishing a connection and receiving a signal, data exchange with the remote control commences, and the need for continued operation is assessed. If the operation concludes, the cycle terminates. Otherwise, cyclical interaction with the remote control persists until the operation concludes.

The algorithm for the control panel operations (figure 4) commences with initialization. Subsequently, the remote control, functioning as a receiver, awaits a free connection request to the robotic intelligent platform. In the absence of active requests, it cyclically waits for a connection request. Upon establishing a connection and receiving a signal, data exchange with the platform is initiated, and the need for continued operation is evaluated. If the operation concludes, the cycle terminates.

3.4. System characteristics

The activation of the data recording system for constructing a three-dimensional model of the reservoir bottom involves checking the system activation, initiating the GPS and SD modules, and configuring their operational settings. The GPS module requires time to connect to satellites and determine its coordinates, hence determining the robotic platform's location is time-consuming. Subsequently, a file is created for recording depth sensor data and corresponding coordinates. A timer, set to 10 minutes by default, is also initiated. During this period, data is recorded in the created file. The coordinates and depth are cyclically read and this data is written to the file at 30-second intervals for the duration set by the timer. This data file serves as the foundation for constructing a wavelet diagram of the reservoir bottom section. If the data recording system is reactivated, it checks whether the module's coordinates are determined, and the cycle continues. If not, the system awaits reactivation.

Radio modules facilitate the transmission of control signals from the remote control, which govern the platform's movement, the activation/deactivation of dimensions. Additionally, data received from sensors, including water acidity level, water turbidity level, temperature, depth, level of harmful gases, platform location coordinates, and battery charge level, is transferred. To construct a map of the bottom relief, data on the reservoir's depth is first collected using an ultrasonic distance sensor. Two additional parameters, time and coordinates, are required to build a three-dimensional model. The coordinates are determined using the GPS data of the mobile platform's location on the reservoir. During research, a site on the reservoir is selected and as the platform moves step-by-step through the reservoir, data from the depth

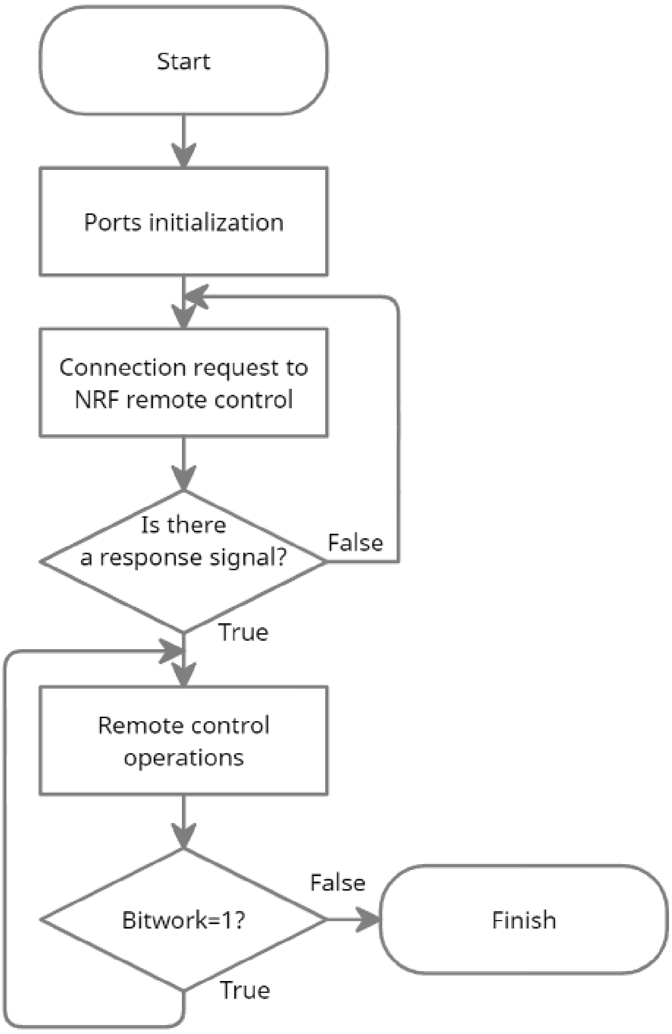

Figure 3: The basic algorithm of the robotic intelligent platform.

sensor and coordinates at these points are collected and recorded on a file on the Raspberry Pi mini-computer.

3.5. Data processing for edge computing

The MATLAB system was utilized for data processing and constructing a three-dimensional relief model of the reservoir bottom, specifically employing the Wavelet Toolbox. This toolbox offers functions and applications for the analysis and synthesis of signals and images. It encompasses algorithms for continuous wavelet analysis, wavelet coherence, synchrosqueezing, and data-adaptive time-frequency analysis.

Continuous wavelet analysis enables the study of the evolution of spectral functions over time, identification of common time-varying patterns in two signals, and execution of time-

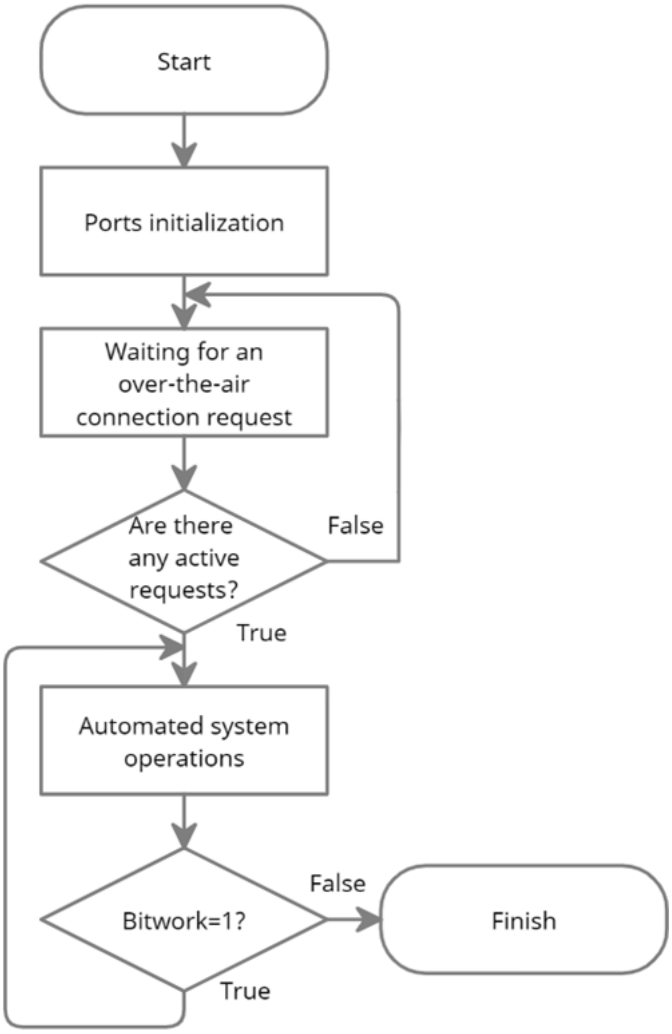

Figure 4: The basic algorithms of the control panel.

localized filtering. Discrete wavelet analysis aids in analyzing signals and images across various extensions to detect discontinuities and other defects that are not readily apparent in the raw data. Furthermore, it allows for the comparison of signal statistics on multiple scales and the execution of a fractal analysis of the data to uncover hidden patterns.

The Wavelet Toolbox also facilitates obtaining a sparse representation of data, which is suitable for denoising or compressing data while preserving essential features. Many of the toolbox functions support C/C++ code generation.

However, the investigation results indicate that the use of wavelet transformations at the current stage of work may not be entirely suitable. It is imperative to adhere to a clear path when using wavelet transformations. For example, it is vital to select the coordinates of a specific section, which are autonomously traversed by the platform at a consistent speed and passes, thereby eliminating measurement errors due to external factors.

A1 f_x 9:42:34

	A	B	C	D	E	F	G
1	9:42:34	50.236396	28.611356	155	24	6	5
2	9:42:37	50.236400	28.611360	146	24	6	5
3	9:42:40	50.236412	28.611358	140	30	6	4
4	9:42:43	50.236412	28.611354	134	29	6	4
5	9:42:46	50.236415	28.611351	145	29	6	4
6	9:42:49	50.236412	28.611351	132	30	6	4
7	9:42:52	50.236396	28.611356	144	30	6	4
8	9:42:55	50.236385	28.611362	144	30	6	4
9	9:42:58	50.236381	28.611370	135	30	6	4
10	9:43:01	50.236377	28.611373	151	30	6	4
11	9:43:04	50.236373	28.611377	136	30	6	4
12	9:43:07	50.236370	28.611379	147	30	6	4
13	9:43:10	50.236362	28.611383	156	29	6	4
14	9:43:13	50.236358	28.611383	131	29	6	4
15	9:43:16	50.236354	28.611383	138	29	6	4
16	9:43:19	50.236354	28.611381	147	29	6	4
17	9:43:22	50.236354	28.611377	149	29	6	4
18	9:43:25	50.236354	28.611375	99	29	6	4
19	9:43:28	50.236354	28.611371	89	29	6	4
20	9:43:31	50.236354	28.611370	96	29	7	4
21	9:43:34	50.236358	28.611366	105	30	6	4

Figure 5: Recorded data from a flash drive [6].

4. Experiment

Prior to the experiment, a comprehensive check was conducted to ensure the efficiency of the platform and all its components. A shallow water body was then selected for the test launch of the intelligent robotic platform and for the collection of necessary data. A route with varying trajectories was traversed, and sensor data were recorded, which constituted the primary objective of the research.

All the research data was recorded in a file and stored on a flash drive for convenience in subsequent processing and analysis. A portion of the recorded data is depicted in figure 5.

The GPS module ascertains the current location and provides the exact time corresponding to the location in specific coordinates. The analysis of this data enables the construction of a map of the intelligent robotic platform's route and a two-dimensional depth graph, as shown in figure 6.

Moreover, a three-dimensional model of the reservoir bottom was constructed based on the data from the platform's route and measurements taken at specific points along the route. However, this model lacks high detail as it only considers the specified points of the route. To

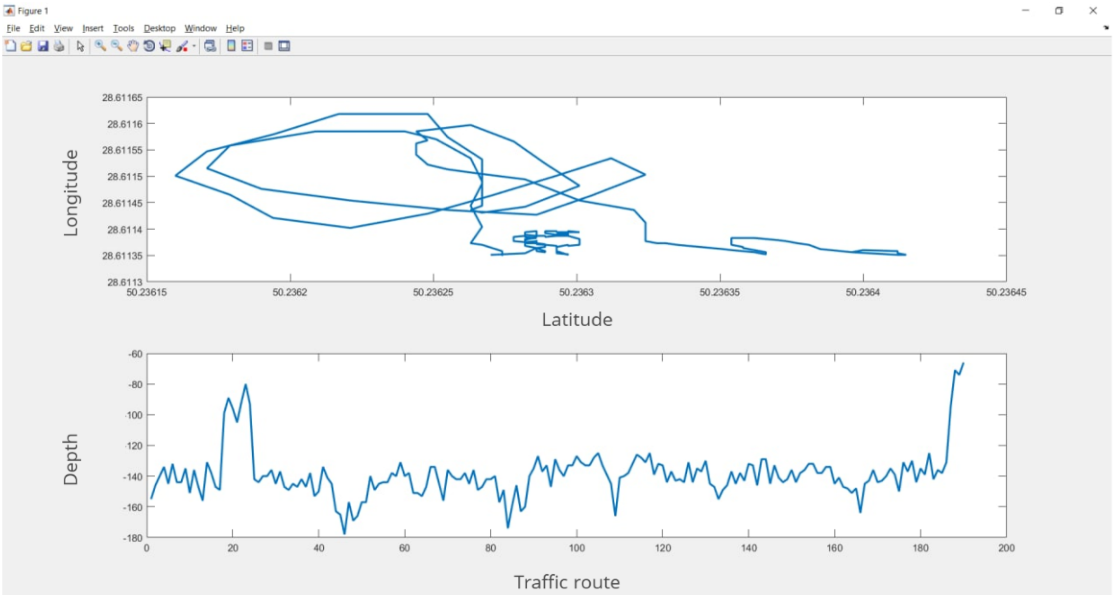

Figure 6: Intelligent robotic platform movement route and two-dimensional depth plot.

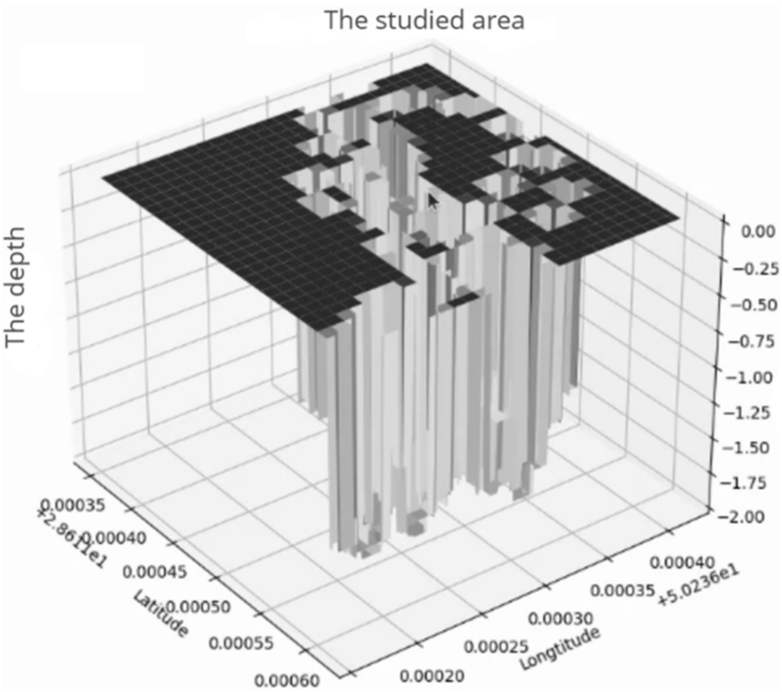

Figure 7: Three-dimensional model of the bottom of the reservoir [6].

enhance its informativeness, all intermediate points must be populated with relevant data, as illustrated in figure 7.

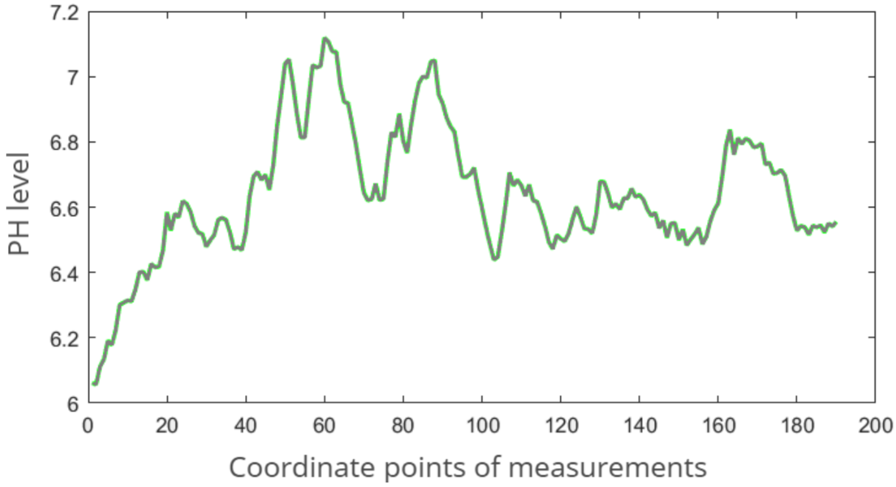

Figure 8: Changes in water acidity in the reservoir.

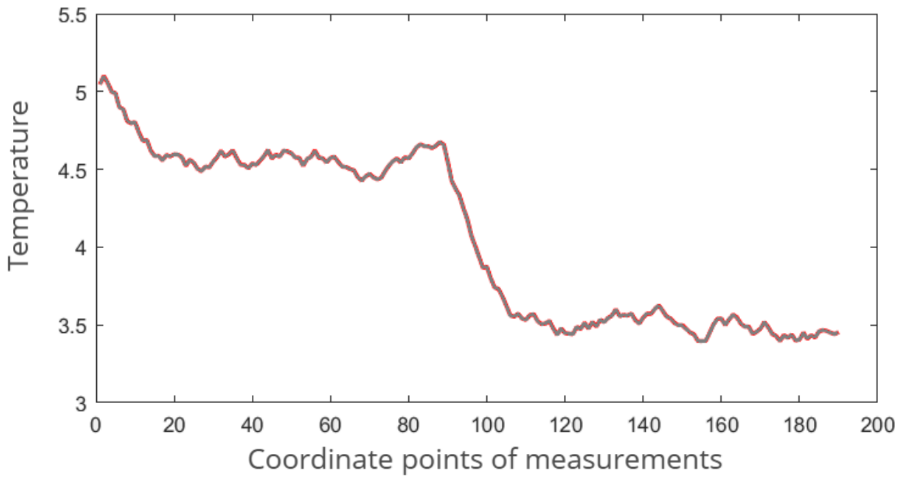

Figure 9: Water temperature changes in the reservoir.

Based on the readings from the temperature and acidity sensor at each determined point along the robotic platform's route, graphs depicting changes in these values were constructed, as shown in figures 8 and 9.

5. Conclusions

This research presents a novel intelligent robotic platform designed for geodetic and ecological investigations of water bodies. The platform is capable of assessing water quality and measuring the depth of a water body. It provides a comprehensive layout of all structural elements, elucidates the methodology, and clarifies subsequent data processing. Key system elements such as temperature, gas sensor, water acidity, water turbidity sensors, video camera were selected, which fulfill all platform installation requirements.

The system's effectiveness and accuracy were evaluated on a natural reservoir (a river). All necessary measurements. Based on these results, conclusions were drawn about the water quality in the reservoir. Furthermore, three-dimensional models of the studied bottom area and graphs depicting changes in values (temperature, turbidity and acidity) were constructed. The research also underscores the challenge of using a wavelet diagram to describe the area of the reservoir bottom.

The system possesses a range of functions, which can be expanded in the future. For instance, the function of autonomous work at specified points could be added, contributing to the construction of a detailed map of the reservoir bottom. Additionally, the article contemplates the possibility of a more localized and detailed analysis of water.

References

[1] Bezvesilna, O., Tkachuk, A., Chepyuk, L., Nechai, S. and Khylchenko, T., 2017. Introducing the principle of constructing an aviation gravimetric system with any type of gravimeter. *Eastern-European Journal of Enterprise Technologies*, 1(7(85)), pp.45–56. Available from: https://doi.org/10.15587/1729-4061.2017.92941.

[2] Brans, P., 2021. What Norwegians are learning as they pioneer autonomous ships. Available from: https://tinyurl.com/4pcatcdt.

[3] Chung, H.Y., Chung, Y.L. and Hung, Y.J., 2018. An Effective Hexapod Robot Control Design Based on a Fuzzy Neural Network and a Kalman Filter. *2018 IEEE Region Ten Symposium (Tensymp)*. pp.248–253. Available from: https://doi.org/10.1109/TENCONSpring.2018.8691947.

[4] Dimitropoulos, S., 2019. The New Ocean Explorers. Available from: https://www.popularmechanics.com/technology/infrastructure/a29849406/unmanned-ocean-drones-antarctic-voyage/.

[5] Drăgan, O., 2021. This Solar-Powered Electric Ferry Is the First Maritime Robotaxi in Europe. Available from: https://tinyurl.com/4bf65wut.

[6] Georgivskyi, D., Tkachuk, A. and Yanchuk, V., 2021. A robotic platform for carrying out geodetic and ecological surveys of water bodies. *Abstracts of reports of the XII International Scientific and Technical Conference "Information and Computer Technologies - 2021"*. pp.192–194. Available from: https://conf.ztu.edu.ua/informatsijno-kompyuterni-tehnologiyi-2021-1-3-kvitnya-2021-r/.

[7] Koval', A.V., 2015. Simulation of gravimetric measurements by gyroscopic integrator of linear accelerations. *Gyroscopy and Navigation*, 6, pp.344–347. Available from: https://doi.org/10.1134/S2075108715040070.

[8] Li, Y., Wang, X., Zhao, Z., Han, S. and Liu, Z., 2020. Lagoon water quality monitoring based on digital image analysis and machine learning estimators. *Water Research*, 172, p.115471. Available from: https://doi.org/10.1016/j.watres.2020.115471.

[9] Nevyedrov, M., Tkachuk, A. and Hrynevych, M., 2023. Surface robotic platform. *Abstracts of the All-Ukrainian scientific and practical on-line conference of higher education graduates*

and young scientists dedicated to Science Day. p.118. Available from: https://conf.ztu.edu.ua/konferentsiya-prysvyachena-dnyu-nauky-15-19-travnya-2023-r/.

[10] Niiler, E., 2020. The Robot Ships Are Coming … Eventually. Available from: https://www.wired.com/story/mayflower-autonomous-ships.

[11] Rivero, N., 2022. Japan is home to the world's first autonomous container ships. Available from: https://tinyurl.com/bdfpdf7e.

[12] Sea Machines, 2023. SM300 Autonomous Command & Control. Available from: https://sea-machines.com/sm300.

[13] Tedeschi, F. and Carbone, G., 2014. Design Issues for Hexapod Walking Robots. *Robotics*, 3, pp.181–206. Available from: https://doi.org/10.3390/robotics3020181.

[14] Tkachuk, A., Hrynevych, M., Vakaliuk, T., Chernysh, O. and Medvediev, M., 2022. An Intelligent Robotic Platform for Conducting Geodetic and Ecological Surveys of Water Bodies. *Proceedings of the 5th Workshop for Young Scientists in Computer Science and Software Engineering - Volume 1: CS&SE@SW*. INSTICC, SciTePress, pp.50–56. Available from: https://doi.org/10.5220/0012009600003561.