Informationally-technological provision of environmental nature reserves monitoring

Oleksandr Tymchenko [1,2,*,†], Bohdana Havrysh [3,*,†], Orest Khamula [2,*,†] Bohdan Kovalskyi [2,†] and Igor Bagniuk[2,†]

[1] *University of Warmia and Mazury, Ochapowskiego str,2, Olsztyn, 10-719, Poland*
[2] *Ukrainian Academy of Printing, Pidholosko st., 19, Lviv, 79020, Ukraine*
[3] *Lviv Polytechnic National University, Stepana Bandery Street, 12, Lviv, 79000, Ukraine*

Abstract

Modern approaches to environmental protection do not always meet the requirements of science and are often based on the principles of prohibition rather than rational use of natural resources. The analysis of human society development shows the inevitability of the natural environment radical transformation by man, therefore the "prohibitive" approach cannot solve the problem of environmental preservation and stop the destruction of nature. For the harmonious development of nature and man, the policy of nature protection must be built based on the modern science achievements, first of all, on the results of evolutionary and ecological research. Ecological monitoring is the most important part of the study and protection of the environment, since the analysis of natural processes dynamics makes it possible to reveal the regularities of the ecosystems organization and the biology of individual species of animals and plants. Therefore, the development of ecological monitoring methods is urgent, especially for nature reserves, which would allow not only to record changes and violations, but also to identify the causes and predict the direction and nature of their further transformation. The physical and chemical parameters of the environment are usually measured with the help of devices: the magnitude and spectrum of noise, temperature, characteristics of electromagnetic fields, characteristics of radioactive pollution of the environment, characteristics of geophysical phenomena, concentrations of chemical pollutants in air, water, soil, etc. Remote research of ecological systems from airplanes, artificial Earth satellites, and spaceships is widely used. Monitoring methods are divided into qualitative and quantitative. Qualitative analysis usually precedes quantitative determinations. Based on the measured parameters, methods of quantitative analysis are divided into chemical, physico-chemical, physical and biological. Thus, the existing methods of environmental monitoring are narrowly focused and relate to the measurement of quantitative parameters. There is a lack of methods considering the informational and technical component of the monitoring and research process.

Keywords

ecological monitoring of nature reserves, wireless sensor network

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* Corresponding author.
† These authors contributed equally.
olexandr.tymchenko@uwm.edu.pl (O. Tymchenko); dana.havrysh@gmail.com (B. Havrysh); khamula@gmail.com (O. Khamula); bkovalskyi@ukr.net (B. Kovalskyi); irapb0k@dmail.com (I. Bagniuk)
0000-0001-6315-9375 (O. Tymchenko); 0000-0003-3213-9747 (B. Havrysh); 0000-0003-0926-9156 (O. Khamula); 0000-0001-9088-1144 (B. Kovalskyi); 0009-0005-6460-430X (I. Bagniuk)

1. Introduction

Traditional methods of the environment state monitoring are based on changes observations in individual elements of natural ecosystems (fluctuations in climatic factors, natural or anthropogenic habitat disturbances, changes in the number of individual species of animals and plants, etc.). In such studies, the main attention is paid to the study of the structure and nature of connections between individual elements and the evolution of connections over time. This is due to the dominance of the population approach noticed in recent ecological researches.Scientists' attention was focused mainly on discovering the population structure of individual species of organisms. The biosystems as integral aggregates of cells, as well as individuals, and species makes a significant amendment to the traditional perception of the organic world and the nature of its development. It was forced to raise and solve methodological issues of studying biosystems differently than it was before. Such studies focus on the structure and nature of the connections between individual elements and the evolution of connections over time. These indicators allow us to characterize the biosystem as a whole and establish the laws governing its development It is these indicators that make it possible to characterize the biosystem as a whole and establish the laws governing its development. Therefore, it is obvious that modern methods of environmental monitoring should be based, first of all, on the analysis of the mechanisms of changes in the structure of the ecosystem as a whole [1].

Reserves organize monitoring with the help of so-called trial sites, permanent or temporary routes. As a rule, each site has a passport and all collected information is entered into it. The routes and sites form a monitoring network, the collection of materials has been conducted at the same points for many years and according to the same methodology [1].

The large amount of data that is created because of such research already makes their manual processing impossible, which makes the task of developing appropriate information systems especially urgent.

The trends and features analysis of the development of nature reserves and ecological monitoring methods and the requirements for the development of specific programs for its implementation allows us to draw conclusions about insufficient attention to the technical and informational support of these processes. At the same time, the use of information technologies in the processes of environmental monitoring can not only improve its individual aspects, but also introduce fundamentally new methods of research. In particular, the use of artificial intelligence systems, for example, the study of the state of populations of rare species.

The purpose of the work is the development of methodical and algorithmic support for the informational support of the tasks of ecological monitoring of nature reserves.

2. Related works

In accordance with the above, all connections in ecosystems are subordinate in nature [1, 10]. There are leading ecological factors that determine species diversity and other features of species biology, and secondary factors that are not so significant for the structure and functioning of communities. The identification of such factors and the nature of their relationship on the example of background species of animals and plants makes it possible to monitor based on the analysis of changes in hierarchically organized relationships of organisms [1-3].

Fire alarm system. Thousands of microscopic sensors are spread over the territory, for example, a forest, and in a threatening situation, on the basis of continuous temperature measurements, they inform the crisis center about the existing threat. Thanks to the sensors, a quick reaction is possible, and because of this, losses are minimized.

Flood warning system. The US uses the ALERT system, which warns against dangerous atmospheric phenomena (floods, hurricanes). Several types of sensors monitor the amount of precipitation, water level in rivers and other, most meteorological information, and the collected information is forwarded to a central database and analyzed. Thanks to this, it is possible to better predict threats.

However, systematic landscape studies are not conducted in all reserves. In most of them, only minimal observations are made: temperature, soil moisture, and information on natural disasters that have already occurred and are recorded: avalanches, changes in the coastline, landslides, landslides, and so on. This is due to the lack of specialists and the laboriousness of research. Therefore, data on the dynamics of the soil cover over a long period are not available in many reserves. The use of wireless sensor networks makes it easier to obtain relevant data, and in many cases to predict threatening changes.

In addition, there are many *systems that monitor the preservation of animals, pollution of the natural environment, or the condition of soils in agriculture.* The importance of rare animal species for systematic environmental monitoring is due to the fact that their existence is supported by limited resources. Even a slight change in ecosystem connections can have a significant impact on the state of populations of rare species. Therefore, rare species of animals are sensitive indicators of the state of natural ecosystems [4, 6]. The use of observation sites does not allow us to cover large areas and identify connections and threats that are important for all populations.

The application of systematic ecological monitoring using wireless sensor networks makes it possible to significantly expand the scope and research details without human intervention. Methods allows combining these often unrelated observations and effectively use them to analyze the state and change in the structure of natural ecosystems [5-7].

3. Selection of the monitoring structure

Typically, a network-level environmental data collection program is characterized by the presence of a large number of nodes that continuously receive and transmit data to base stations that store it for later use. In general, the use of wireless sensor networks (WSNs) requires very low data rates and extremely long operational periods. Usually, network nodes are distributed over a controlled area. The distance between neighbouring nodes can be different, but the length of the network is usually large [8, 9].

Sensor networks can work in various and extreme conditions. Therefore, to perform monitoring tasks, we can also place them in the following places:

- roads;
- places of biological and chemical pollution;
- on animals, to monitor their conservation;
- in many hard-to-reach places.

In sensor networks based on wireless environment, energy consumption is very important. Sensor nodes can be equipped with a rather limited power source (<0.5Ah, 1.2V). Although there are sensor nodes with replenishment of energy from the sun or vibrations, in many cases it is not possible to replace the energy sources, due to which the lifetime of the node is strongly dependent on battery resources. In addition, in sensor networks with serial data transmission, each node must fulfil the dual role of data source and routing data. Therefore, the loss of functions of several nodes can have a significant impact on topology changes, as well as require data for re-routing and reorganization of the entire network.

After deployment, individual WSNs nodes must initiate a route discovery procedure to generate network topology and evaluate optimal routing strategies. This strategy can be used to route measurement data to a central collection point [11, 17].

Most environmental data collection applications use a tree-based routing topology, where each routing tree is rooted at resource-intensive nodes or base stations. This data is periodically transmitted from child nodes to parent nodes until it reaches the base station. In a typical data collection scheme based on a tree topology, each individual node is responsible for routing or forwarding data received from all its descendants [11, 13].

Nodes with a large number of descendants transmit significantly more data than leaf nodes, causing more energy consumption. As a result, these nodes can quickly become energy consumption bottlenecks for WSNs.

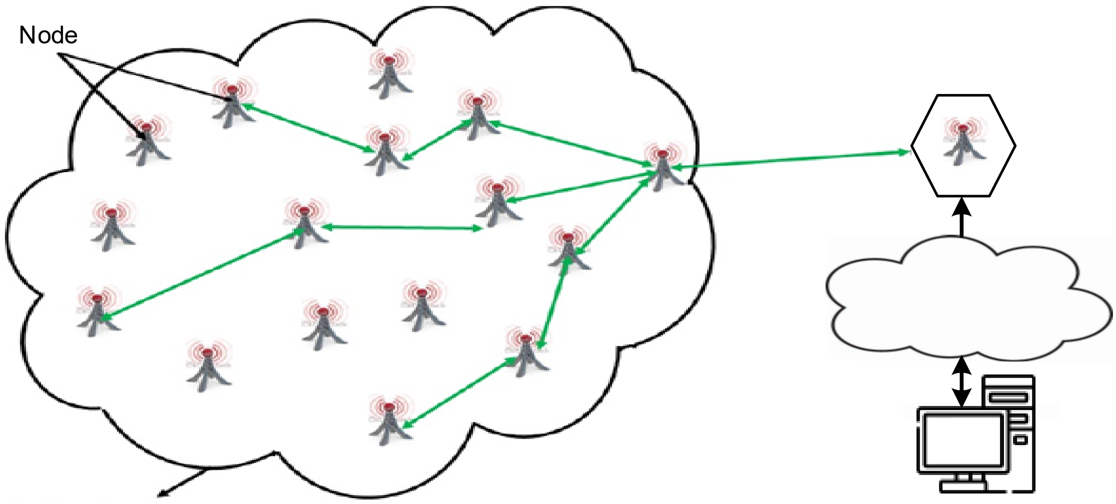

Figure 1: Typical architecture of WSNs of environmental monitoring.

After setting up the WSNs, each node periodically takes sensor readings and transmits the collected data to the main node (Fig. 1). A typical transmission period is estimated to be in the range of 1 to 15 minutes [12-15]. In typical environmental monitoring conditions, attributes such as air and soil temperature, light intensity, and air and soil moisture change slowly and therefore do not require shorter reporting periods.

Data sampling can be delayed within the network for a period of time without significantly impacting application performance. Often, this data is stored for further analysis, not for real-time operations.

To meet operational requirements for WSNs, each transmission must be precisely planned. A work/sleep protocol is often used, where nodes will sleep most of the time to save energy and only wake up to transmit or receive data. If the nodes deviate from this schedule, then the data transfer will fail [11, 16].

Due to limited energy resources, there is always a possibility that nodes will fail and routes will be disrupted. As a result, periodic network configuration updates must occur to redistribute the network load or to handle node or link failure. Additionally, network users may want to change the network topology to accommodate new information about the controlled environment. In general, network reconfiguration is rare and has no significant impact on overall energy consumption [18, 19].

Key environmental monitoring parameters are network uptime, accurate clock synchronization, low data rates, and static topologies. Nor is it usually important that network data be transmitted in real time. This data may be temporarily stored, aggregated or, if necessary, delayed in the network [20].

To reduce the total energy consumption and increase the total monitoring time, it is advisable to change the traditional tree-shaped structure of the WSNs to a hierarchical one (Fig. 2.).

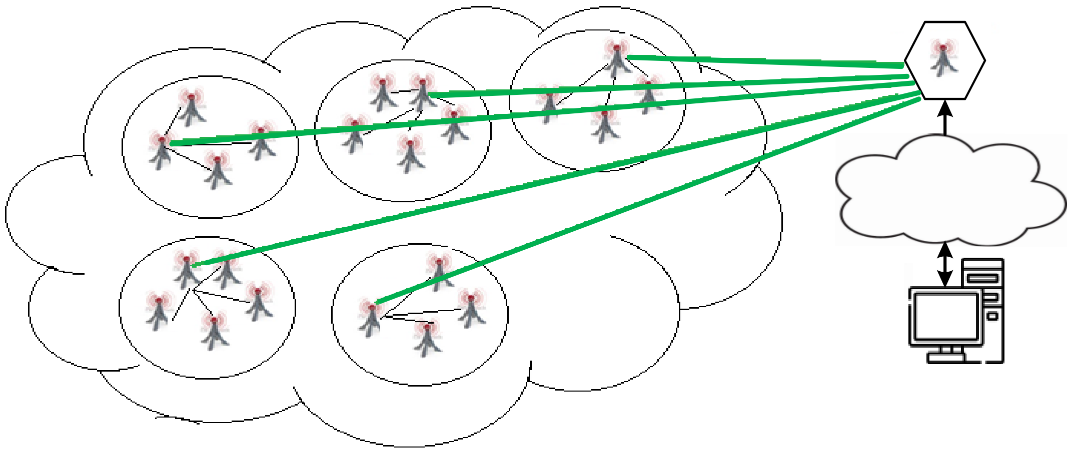

Figure 2: Hierarchical structure.

Hierarchical protocols (Fig. 2) (for example, LEACH protocol (Low-Energy Adaptive Clustering Hierarchy) [10, 21] or low-energy adaptive hierarchy of groups, clusters) divide the network into clusters consisting of groups of nodes. One of the nodes in the cluster receives the status of the master, and other nodes in the network maintain communication within the cluster only with it. The main node instead forwards the information further to the main node in the network and only it maintains communication with it. The protocol allows a random change of the main nodes in the clusters, which made it possible to reduce energy use and evenly distribute the energy load on all nodes in the network. In addition, LEACH performs data aggregation, which significantly limits the amount of data that is broadcast to the master node.

Example. The simulation of wireless sensor networks was performed using the SNOW simulator [4].

Simulations of energy properties were aimed at determining the lifetime and energy consumption for individual sensors in the network. These parameters are essential for wireless sensor networks, because it is not desirable to have a situation in which only a few sensors in the network operate for much longer. Obviously, the best solution is when all sensors in the network are loaded evenly, which means that their lifetime is approximately the same. For simulations, we used a random placement of 50 nodes on an area of 100 by 100 meters.

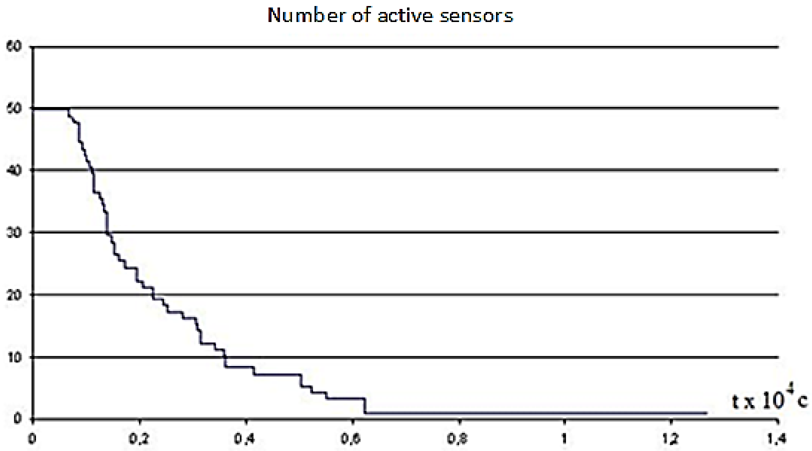

Figure 3: Number of active sensors for a protocol with a homogeneous structure.

The simulation also revealed a serious drawback of using protocols with a homogeneous structure. Such wireless sensor networks excessively load the nodes closest to the head node. This situation is obviously not desirable, it causes uneven load of nodes in the network, which reduces its operation time (Fig. 3).

Protocols of this type, with an increasing number of nodes are functioning worse and worse, creating excessive traffic, which significantly reduces the network lifetime. From our point of view, the best network is the one in which all nodes live as long as possible and "die" at the same time. Only a hierarchical network can fulfill such requirements for a good network in terms of energy parameters.

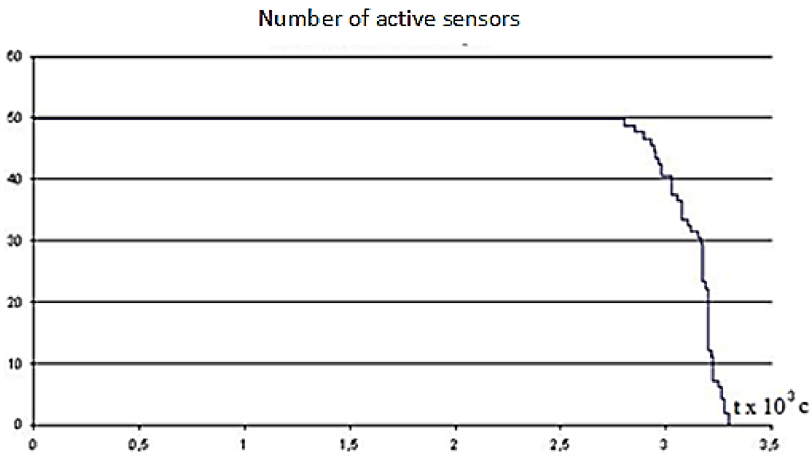

Figure 4: Number of active sensors for protocols with a hierarchical structure.

Protocols with a hierarchical structure have a small delay in packet transmission, regardless of the number of nodes. The entire network is loaded evenly and there are no situations when some sensors remain unnecessary, being outside the network. However, the significant advantages of protocols with a hierarchical structure are offset by the need for significant sensor processor power, as well as the time intervals required to fix the network structure.

3.1. Solving the tasks of ecological monitoring of nature reserves with the use of information technologies

Let's define the tasks of ecological monitoring of reserves, which can be solved with the use of information technologies:

- the use of spatial databases to collect and store information on the values of controlled parameters and meteorological indicators tied to specific spatial objects;
- development of environmental monitoring subsystems of nature reserves to support decision-making in the field of environmental safety and to ensure software and analytical solutions to monitoring task;
- development of standards and protocols for the exchange of information between subsystems of environmental monitoring of all levels, including protocols for the transfer of information received at automated environmental monitoring posts, and protocols for the transfer of information to the international level;
- use of the combined services of global data dissemination [22, 23] and global telecommunications systems [22] for the transmission of information;
- development of software interfaces for organizing user interaction with monitoring subsystems, taking into account the level of access [22, 24].

Solving the specified environmental monitoring tasks is possible in an information system capable of performing such functions [23]:

- collection and storage in a spatial database of information coming from monitoring subjects and automated monitoring posts;
- automatic notification of personnel in the event of dangerous situations by analyzing information in real time;
- informational and analytical support for decision-making in the field of environmental monitoring at all levels;
- generation of reports, including in the form of map information for system users according to access rights;
- solutions to typical problems (modeling concentration fields, forecasting the dynamics of changes in concentrations or populations) at all levels;
- information security [5, 25].

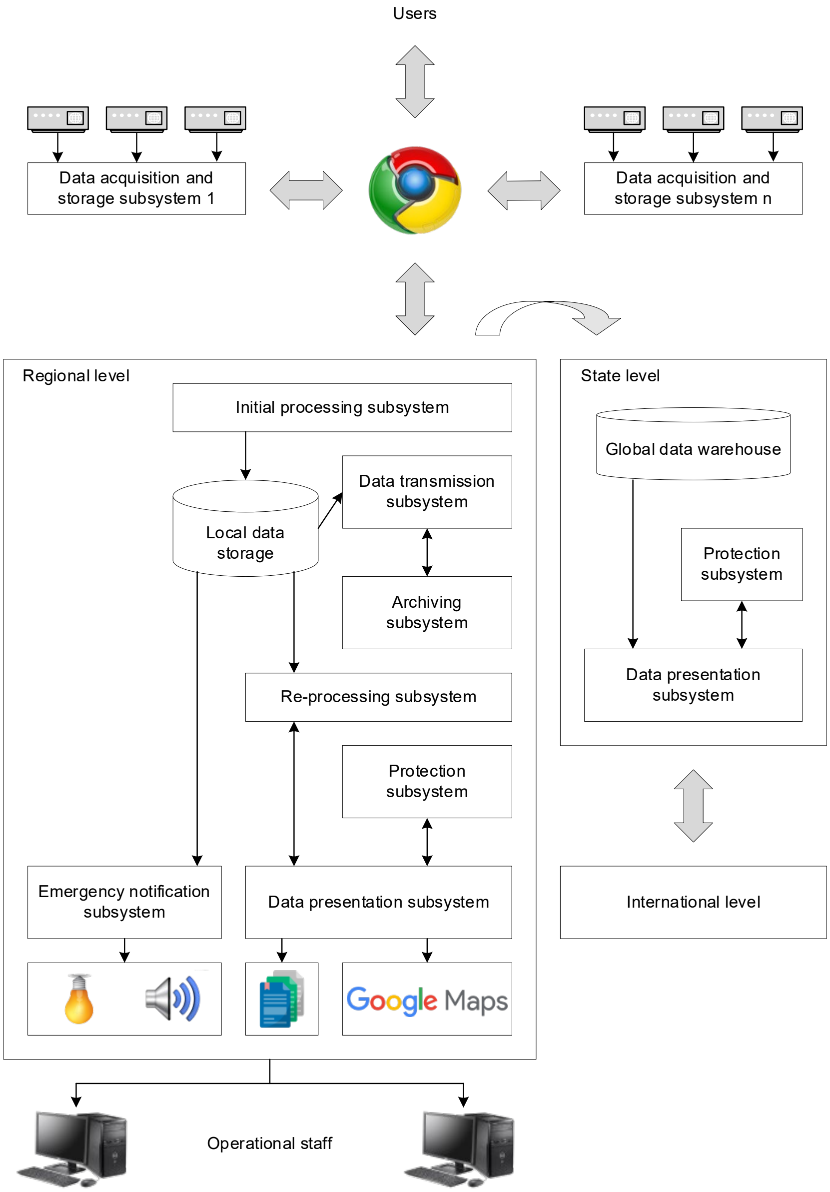

Figure 5: Structure and information flows in the environmental monitoring system.

To ensure such functionality, the following subsystems can be distinguished in the structure of the information system of ecological monitoring of nature reserves (Fig. 5) [25]:

- the data collection and storage subsystem is a set of the same type of automated environmental monitoring stations and typical modular systems and is intended for measuring the concentration of pollutants in the soil and atmosphere, monitoring meteorological parameters, the level of solar radiation, ionizing radiation, etc.;
- the initial processing subsystem (Fig. 5) is intended for preliminary processing of information coming from the data collection and accumulation subsystem. This subsystem allows control of data transmission at the physical and logical levels. The

subsystem can also carry out primary conversions, convert units of measurement according to international standards, etc.

- local data storage (LDS) is a spatial database and is designed to store observation data. All information is stored in its original form. This makes it possible to ensure a regular flow of data. In the LDS design process, it is necessary to take into account the possibility of storing any information about the state of control objects in real time [22, 25];
- the data reprocessing and interpretation subsystem is a software block that concentrates a large part of the system performed functions. This subsystem is designed to solve typical monitoring tasks (modeling concentration fields, forecasting the dynamics of changes in concentrations or populations, supporting decision-making, etc.);
- global data storage (GDS) accumulates information coming from local level objects. The basis of the GDS is a distributed database that uses information replication technologies and enables data recovery in the event of emergency situations;
- the data exchange subsystem can use data transmission in the GDS and can be implemented as a software module [25].

Data can be transmitted in binary or XML format. The specified subsystem can also summarize data before sending it to the GDS. The subsystem of providing data to operational personnel is used to visualize the data obtained as a result of the analysis and presented in the form of:

- reports, the form of which corresponds to international and national standards. In the process of developing the subsystem of providing information, modern technologies of document formation can be used;
- maps that display the state of observed values in the form of fields. Such values can be the current levels of pollution or the distribution of meteorological parameters. Google Maps® or Google Earth® technology can be used to build a state map. Google Maps and Google Earth services are open resources and are intended for visualization of various thematic data;
- graphs of time series of observation parameters [2, 25].

In the process of developing this subsystem, a combined approach can be used. For example, the geographic location of monitoring posts can be displayed on a Google map, and when one of them is selected, the related reporting documentation or observation data can be searched [2, 13, 21].

- the emergency notification subsystem is intended for automatic notification of operative personnel in the event of dangerous situations in the territory of the region associated with a sharp change in the values of the observed parameters. An example of a dangerous event can be a sharp increase in the value of an observed value (for example, the concentration of a pollutant) and its departure from the established norms.
- the archiving subsystem serves for automatic archiving of collected information. Archiving parameters can be set by the operator in wide ranges;
- the information protection subsystem is designed to protect information from illegal access (if necessary by encryption) and control access to the system [2, 13, 25].

The proposed system is a concept, and the existing systems are characterized by insufficient periodicity of data collection and insufficiently reliable methods of their preservation, limited access to the specified information and almost complete absence of software and technical means of its processing and decision-making support [2, 25]. Therefore, we will further consider a possible option of formalizing the work process of the subsystem of primary information support (subsystem of data collection and accumulation in Fig.5).

3.2. Creation of information support for monitoring systems

The class diagram for WSNs environmental monitoring is shown in Fig. 6. To collect data, sensors use SensorGateway to transmit data over the Internet to a DataServer (smartphone, router, etc.), where the data is stored in a database. Data sources are sensors of environmental parameters.

To use the data, the user (Client) launches the Application or the WebClient web application, which allows him to connect via the Internet to the DataServer, which stores the data (Fig. 6). The DataServer runs the server application, and it serves the client requests by querying the database.

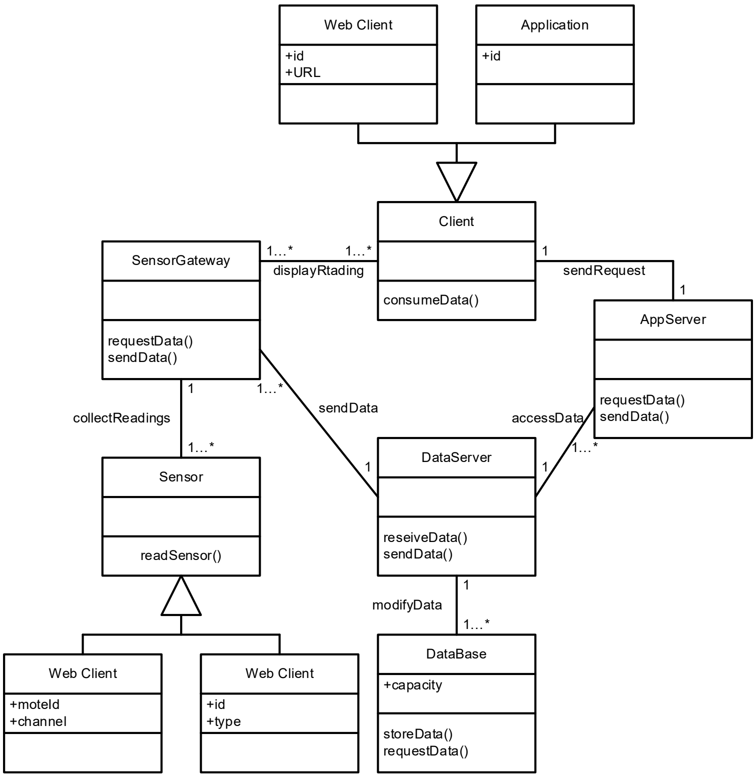

Figure 6: Class diagram for WSNs environmental monitoring.

In fig. 7 shows the sequence diagram of data collection and storage in the environmental monitoring system. The Sensor reads information from sensors based on the signals of the built-in timer and sends the data to the SensorGateway and then to the DataServer, which stores the data in the database.

The data is used in the system in the following sequence (Fig. 8):

- the client forms a data request to the AppServer,
- AppServer requests data from DataServer,
- the DataServer successfully requests data from the database.

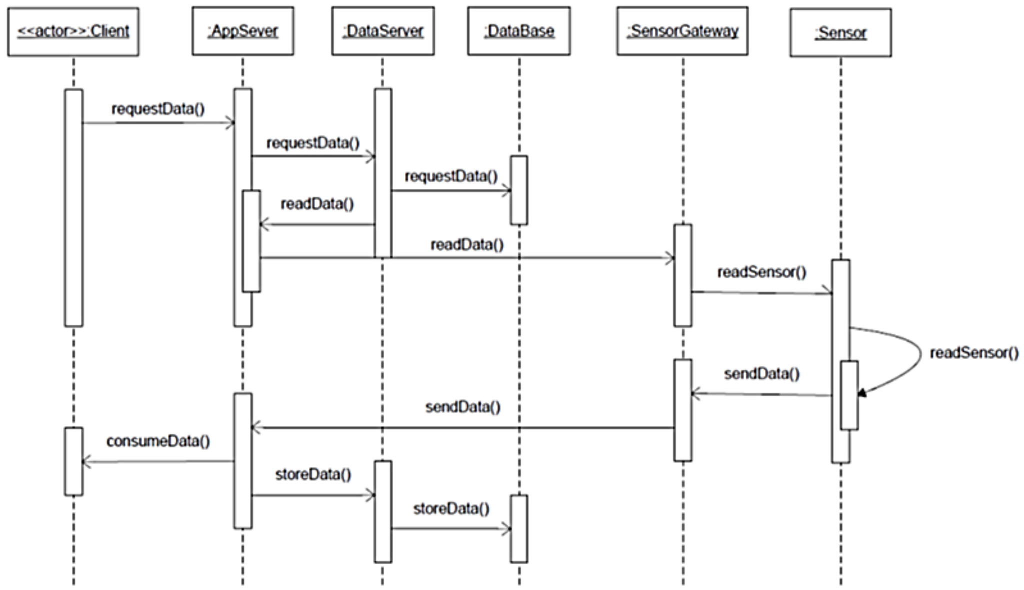

Figure 7: Diagrams of the sequence of data use in the environmental monitoring system in case of their temporary unavailability.

Hypothetically, smoke and fire can be detected by standard sensors of the monitoring system - smoke and temperature sensors. But only if the ignition source is near the wireless network node. In addition, typical WSNs are too slow to send the necessary information to the user program in a timely manner.

Therefore, parallel to the monitoring network, it is worth deploying a new one built on the basis of wireless video cameras (Fig. 8), the main purpose of which will be to detect signs of fire on the territory of the reserve.

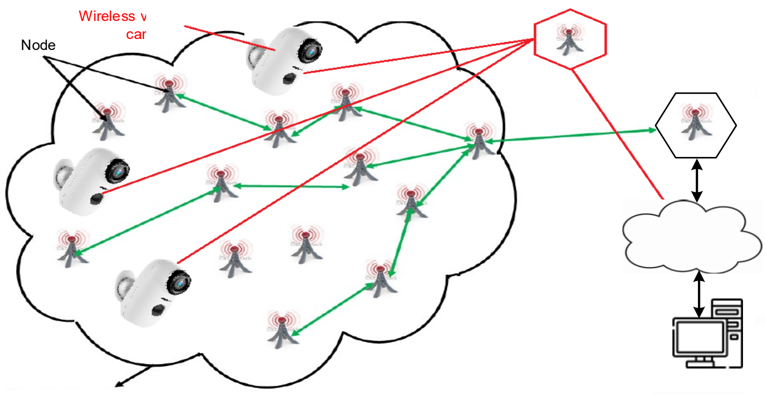

Figure 8: The proposed WSNs architecture for environmental monitoring of nature reserves.

Analysis of data from video cameras for the purpose of detecting signs of fire can be implemented on the basis of artificial vision technologies with appropriate ready-made libraries (for example, OpenCV [20, 25]) and artificial intelligence methods implemented in a number of open libraries, for example, Keras [21, 25].

4. Conclusions and discussion

Current systems of ecological monitoring of natural reserves are characterized by insufficient periodicity of data collection and insufficiently reliable methods of their preservation, limited access to information and almost complete absence of software and technical means of its processing and decision-making support. The analysis of trends and features of ecological monitoring development methods of nature reserves allows us to draw conclusions about insufficient attention to its technical and information support.

For some reason, safety issues are often raised beyond the environmental monitoring procedures, which violates the principle of systematic environmental monitoring. For example, prevention or timely detection of fires.

To implement the program part of the proposed WSNs structure of environmental monitoring of nature reserves based on video surveillance systems to detect signs of fire. Fire in a controlled area, especially with anthropogenic impact, is a very important factor leading to the destruction of protected areas. However, the detection of smoke and fire by wireless sensor network nodes is quite limited in terms of distance. In addition, typical wireless sensor networks are too slow to send the necessary information to the central monitoring node in a timely manner. With the use of appropriate technical and software tools of machine vision, ecological monitoring of nature reserves can be not only fully automated, but also brought to a fundamentally new level, providing continuous monitoring of a certain territory and automatic storage and analysis of results.

The presented study is proposed for the Carpathian Biosphere Reserve for areas of nature with possible changes in relief due to anthropogenic impact.

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References

[1] N. Lu, H. Ma and J. Wang, "Thoughts on the Construction of Unified Spatial Data Manage System for Eco-Environmental Protection," IEEE International Geoscience and Remote Sensing Symposium, Yokohama, Japan, 2019, pp. 4352-4355, doi: 10.1109/IGARSS.2019.8899224.

[2] C. -M. Yang, K. -P. Shih and S. -H. Chang, "A Priority-Based Energy Replenishment Scheme for Wireless Rechargeable Sensor Networks," 1st International Conference on Advanced Information Networking and Applications Workshops (WAINA), Taipei, Taiwan, 2017, pp. 547-552.

[3] O. Tymchenko, B. Havrysh, O. Khamula, B. Kovalskyi, S. Vasiuta, I. Lyakh. Methods of Converting Weight Sequences in Digital Subtraction Filtration. International Scientific and

Technical Conference on Computer Sciences and Information Technologies, 2, art. no. 8929750, pp. 32-36.
[4] B. Durnyak, B. Havrysh, O. Tymchenko, M. Zelyanovsky, O. O. Tymchenko and O. Khamula, Intelligent System for Sensor Wireless Network Access: Modeling Methods of Network Construction, IEEE 4th International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS), Lviv, Ukraine, 2018, pp. 93-97, doi: 10.1109/IDAACS-SWS.2018.8525792.
[5] T. Bao, Z. Huang and D. Li, "Data Loss and Reconstruction for Wireless Environmental Sensor Networks," ieee 3rd international conference on big data security on cloud (bigdatasecurity), ieee international conference on high performance and smart computing (hpsc), and ieee international conference on intelligent data and security (ids), Beijing, China, 2017, pp. 48-52, doi: 10.1109/BigDataSecurity.2017.41.
[6] M. Diván, "Applying the Real-Time Monitoring based on Wireless Sensor Networks: The Bajo Giuliani Project," 7th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Noida, India, 2018, pp. 18-24, doi: 10.1109/ICRITO.2018.8748648.
[7] V. Kovtun, T. Altameem, M. Al-Maitah, and W. Kempa, “The Markov Concept of the Energy Efficiency Assessment of the Edge Computing Infrastructure Peripheral Server Functioning over Time,” Electronics, vol. 12, no. 20. MDPI AG, p. 4320, Oct. 18, 2023. doi: 10.3390/electronics12204320.
[8] A. Arsalis et al., "Development of Hybrid Photovoltaic-based Nanogrids for the Energy Rehabilitation of Public Buildings: The BERLIN Project," IEEE International Smart Cities Conference (ISC2), Pafos, Cyprus, 2022, pp. 1-4, doi: 10.1109/ISC255366.2022.9922154.
[9] D. Yan, J. Li, X. Yao and Z. Luan, "Quantifying the Long-Term Expansion and Dieback of Spartina Alterniflora Using Google Earth Engine and Object-Based Hierarchical Random Forest Classification," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 14, pp. 9781-9793, 2021, doi: 10.1109/JSTARS.2021.3114116.
[10] G. Santhanamari, M. J. P. S, D. B, K. S and A. R, "Radar Based Target Detection and Classification," International Conference on Intelligent Systems for Communication, IoT and Security (ICISCoIS), Coimbatore, India, 2023, pp. 412-416, doi: 10.1109/ICISCoIS56541.2023.10100358.
[11] B. Kovalskyi, M. Dubnevych, T. Holubnyk, I. Skarga-Bandurova, L. Maik, Z. Selmenska. Analysis of the Effectiveness of Means to Achieve Optimal Color Balancing in Obtaining a Digital Photographic Image (2022) CEUR Workshop Proceedings, 3156, pp. 520-538.
[12] G. Santhanamari, M. J. P. S, D. B, K. S and A. R, "Radar Based Target Detection and Classification," International Conference on Intelligent Systems for Communication, IoT and Security (ICISCoIS), Coimbatore, India, 2023, pp. 412-416, doi: 10.1109/ICISCoIS56541.2023.10100358.
[13] A. Sarthi, D. S. Gurjar, C. Sai, P. Pattanayak and A. Bhardwaj, "Performance Impact of Hardware Impairments on Wireless Powered Cognitive Radio Sensor Networks," in IEEE Sensors Letters, vol. 4, no. 6, pp. 1-4, June 2020, Art no. 7500704, doi: 10.1109/LSENS.2020.2994595.

[14] J. Gao, R. Wu, J. Hao, C. Xu and H. Guo, "SWIPT-Based Energy Scheduling for Solar-Powered WSN in Full-Duplex Mode," in IEEE Sensors Journal, vol. 22, no. 13, pp. 13668-13681, 1 July1, 2022, doi: 10.1109/JSEN.2022.3174120.

[15] B. Kovalskyi, M. Dubnevych, T. Holubnyk, N. Pysanchyn, B. Havrysh. Development of a technology for eliminating color rendering imperfections in digital photographic images (Open Access) (2019) Eastern-European Journal of Enterprise Technologies, 1 (2-97), pp. 40-47. http://journals.uran.ua/eejet doi: 10.15587/1729-4061.2019.154512.

[16] W. Chen, H. Wang, H. Li, Q. Li, Y. Yang and K. Yang, "Real-Time Garbage Object Detection With Data Augmentation and Feature Fusion Using SUAV Low-Altitude Remote Sensing Images," in IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022, Art no. 6003005, doi: 10.1109/LGRS.2021.3074415.

[17] C. Gao, Z. Wang and Y. Chen, "On the Connectivity of Highly Dynamic Wireless Sensor Networks in Smart Factory," International Conference on Networking and Network Applications (NaNA), Daegu, Korea (South), 2019, pp. 208-212, doi: 10.1109/NaNA.2019.00045.

[18] Y. Nishikawa et al., "Design of stable wireless sensor network for slope monitoring," IEEE Topical Conference on Wireless Sensors and Sensor Networks (WiSNet), Anaheim, CA, USA, 2018, pp. 8-11, doi: 10.1109/WISNET.2018.8311550.

[19] N. I. Sulieman and R. D. Gitlin, "Near-Instant Fault Recovery and Ultra-Reliable Multi-Hop Wireless Sensor Networks," SoutheastCon, Huntsville, AL, USA, 2019, pp. 1-6, doi: 10.1109/SoutheastCon42311.2019.9020455.

[20] A. Rao, H. Shao and X. Yang, "The Design and Implementation of Smart Agricultural Management Platform Based on UAV and Wireless Sensor Network," IEEE 2nd International Conference on Electronics Technology (ICET), Chengdu, China, 2019, pp. 248-252, doi: 10.1109/ELTECH.2019.8839480.

[21] C. Han, L. Ding, L. Sun and J. Guo, "A Node Task Assignment Algorithm for Energy Harvesting Wireless Multimedia Sensor Networks," ICC. IEEE International Conference on Communications, Rome, Italy, 2023, pp. 931-936, doi: 10.1109/ICC45041.2023.10279261.

[22] [N. Abbas and F. Yu, "A Traffic Congestion Control Algorithm for Wireless Multimedia Sensor Networks," IEEE SENSORS, New Delhi, India, 2018, pp. 1-4, doi: 10.1109/ICSENS.2018.8589923.

[23] F. Ertam, I. F. Kilincer, O. Yaman and A. Sengur, "A New IoT Application for Dynamic WiFi based Wireless Sensor Network," International Conference on Electrical Engineering (ICEE), Istanbul, Turkey, 2020, pp. 1-4, doi: 10.1109/ICEE49691.2020.9249771.

[24] E. M. Manuel, V. Pankajakshan and M. T. Mohan, "Efficient Strategies for Signal Aggregation in Low-Power Wireless Sensor Networks With Discrete Transmission Ranges," in IEEE Sensors Letters, vol. 7, no. 3, pp. 1-4, March 2023, Art no. 7500304, doi: 10.1109/LSENS.2023.3250432.

[25] R. Prabha, M. V. Ramesh and V. P. Rangan, "Building Optimal Topologies for Real-Time Wireless Sensor Networks," International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai, India, 2018, pp. 1-6, doi: 10.1109/WiSPNET.2018.8538721.