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Development of a software package for determining key parameters of water bodies required for building an environmental monitoring network

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Abstract. This research discusses an innovative approach to creating an automated system for monitoring water bodies based on modern remote sensing and computer vision technologies. The presented solution is aimed at overcoming the key limitations of traditional environmental monitoring methods, such as high labor intensity, subjectivity of assessments and insufficient efficiency of data acquisition. The developed software package implements a three-stage analysis algorithm: automatic recognition of water bodies on satellite images, calculation of their morphometric characteristics and optimized design of a network of monitoring stations. Particular attention is paid to the adaptability of the system to various types of initial data and shooting conditions, which ensures high accuracy of results even when working with low-quality images. The mathematical foundations of the algorithms, the results of experimental studies and practical recommendations for implementation are described. The results demonstrate the promise of using automated analysis systems to solve environmental monitoring problems in the face of increasing anthropogenic load on aquatic ecosystems.

Keywords: monitoring network design, remote sensing, computer vision, water body detection, automated systems, water monitoring, optimization of the observation network

Authors' contribution. *A.V. Gusev* — conceptualization, development of research methodology, conduct of research, development of software, visualization and analysis of the obtained data, writing, reviewing, and editing of the manuscript. *M.A. Shakhramanyan* —

creation of the research model, scientific management of the research. All authors have read and approved the final version of the manuscript.

Разработка программного комплекса для определения ключевых параметров водных объектов, необходимых для построения сети экологического мониторинга

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Аннотация. Рассмотрен инновационный подход к созданию автоматизированной системы мониторинга водных объектов, основанный на современных технологиях дистанционного зондирования и компьютерного зрения. Представленное решение направлено на преодоление ключевых ограничений традиционных методов экологического мониторинга, таких как высокая трудоемкость, субъективность оценок и недостаточная оперативность получения данных. Разработанный программный комплекс реализует трехэтапный алгоритм анализа: автоматическое распознавание водных объектов на спутниковых снимках, расчет их морфометрических характеристик и оптимизированное проектирование сети мониторинговых станций. Особое внимание уделено адаптивности системы к различным типам исходных данных и условиям съемки, что обеспечивает высокую точность результатов даже при работе с низкокачественными изображениями. Описаны математические основы алгоритмов, результаты экспериментальных исследований и практические рекомендации по внедрению. Результаты демонстрируют перспективность применения автоматизированных систем анализа для решения задач экологического мониторинга в условиях возрастающей антропогенной нагрузки на водные экосистемы.

Ключевые слова: проектирование сетей мониторинга, дистанционное зондирование, компьютерное зрение, детектирование водных объектов, автоматизированные системы, водный мониторинг, оптимизация сети наблюдений

Introduction

Modern problems of environmental monitoring of water bodies require new automated methods for data collection and analysis. Effective management of water pollution requires the use of modern technologies, including intelligent water quality monitoring and management systems [1]. Traditional field research methods have significant features: high labor-intensity, subjectivity of assessments, long measurement time (unable to define online parameter of interest) and insufficient pro-country representativeness. The use of innovative technologies such as artificial intelligence, machine learning and the Internet of Things will enable the implementation of automated real-time water monitoring systems [2]. In this context, remote monitoring systems based on machine detection of post-scan images become particularly relevant.

The developed software package addresses three key issues:

1. Automatic determination of the boundaries of water bodies.

2. Calculation of morphometric characteristics (area, coastline, shoreline).

3. Optimal placement of monitoring stations for the next positioning of environmental monitoring stations to map current concentration fields of priority indicators.

The aim of the work is to develop a software package that will automatically determine the morphometric characteristics of water bodies and based on this, optimize the location of water environmental monitoring stations.

The proposed solution is unique in that it covers everything from the initial processing of satellite or cartographic images to the provision of ready-made recommendations for the location of monitoring stations.

Materials and methods

The methodology is based on multi-level analysis of remote sensing data. In the first step, the system automatically classifies the type of original image as a satellite image or digital map. For each type, special chamois treatments are applied, considering the characteristics of color transmission and spatial resolution.

The pre-processing stage of classified images includes correction for atmospheric distortions, radiometric calibration and geometric reference. An adaptive cloud cover masking algorithm is applied to eliminate the influence of clouds, based on the analysis of spectral characteristics in the near-infrared range. Special attention is given to compendium of the effects of solar illumination and water surface reflections, which can significantly distort the results of automated analysis.

The water surface segmentation procedure is implemented using the NDWI (Normalized Difference Water Index) algorithm [3]. The algorithm is modified with morphological analysis and machine learning methods. The system automatically adapts the threshold values for the allocation of water bodies according to seasonal characteristics and regional characteristics of the territory.

Such models have been successfully applied for the classification, detection and segmentation of objects on satellite images in different regions of the world [4]. They can consider complex spatial and spectral features of images, learning from large amounts of data and adapting to diverse imaging conditions [4].

The morphometric parameters are calculated considering the spatial resolution of the source data and the topographical features of the terrain. In addition to the basic characteristics (area, shoreline length), the system counts a set of derived indicators:

1. Coefficient of shoreline erosion.
2. Water mirror compaction index.
3. Depth gradients of the coastal zone.
4. Degree of water fragmentation.

These parameters are important for subsequent modelling of hydrological processes and assessment of the ecological status of a water body.

The final stage is the design of an optimal network of monitoring stations. This stage is carried out taking into account the uniformity of coverage of the waters, the characteristics of the coastline and the presence of potential sources of pollution.

The software implementation of the complex is developed in Python language, which provides high flexibility, productivity and wide possibilities of integration with other technologies. Specialized libraries such as OpenCV (implementation of detection, filtering and morphological analysis algorithms) and Scikit-image (advanced segmentation and image processing methods) were used to process images and solve computer vision problems. Powerful geospatial analysis tools have been used to work with geodata, including GDAL (reading, writing and converting raster and vector data) and Geopandas (manipulation of geometric objects and spatial queries). The system architecture allows for export of results in formats compatible with industry information systems.

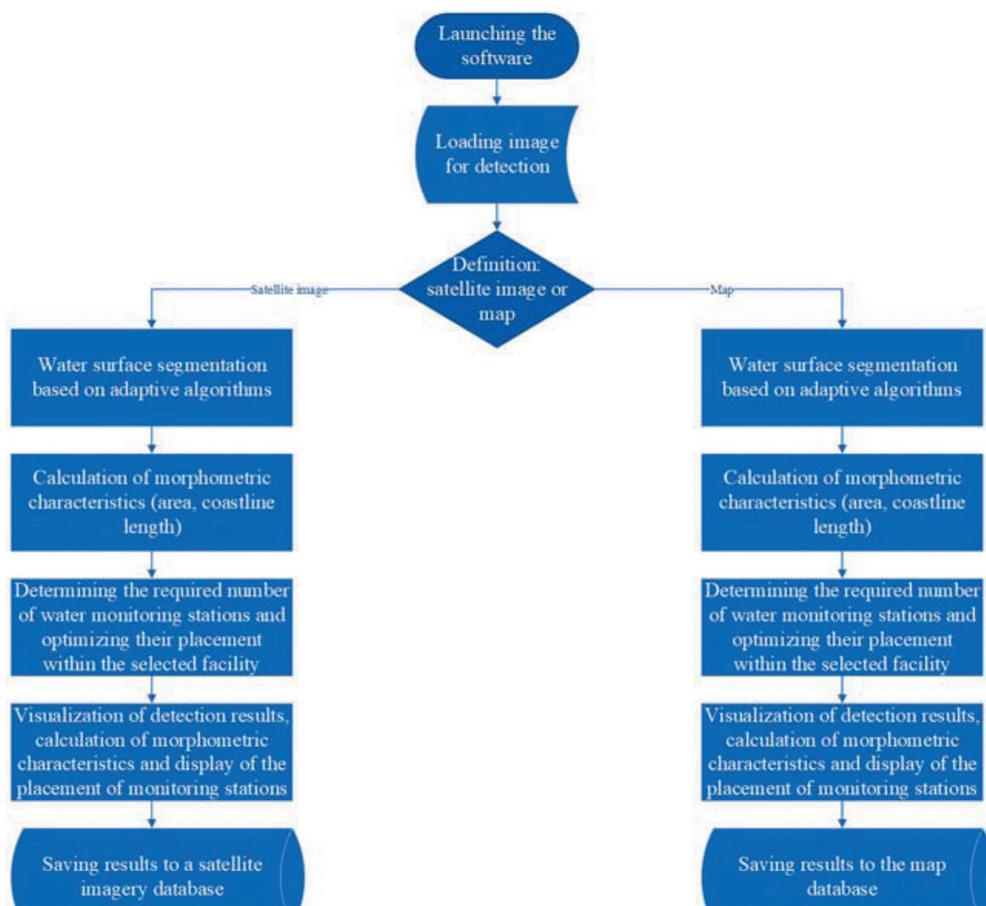Simplified diagram of the software complex is presented in Figure 1.

Figure 1. Block diagram of the hardware and software complex

Source: compiled by A.V. Gusev.

Results and Discussion

The pilot testing of the developed software package was conducted on a variety of water bodies, including natural lakes, reservoirs and river systems. The results demonstrate high efficiency of proposed algorithms for processing remote sensing data and calculation of key parameters of aquatic ecosystems.

The accuracy of automatic determination of water bodies reaches an average of 96%. The greatest differences are observed in areas with intense aquatic vegetation and on sites with complex morphology of coastline. An analysis of these discrepancies has shown that they are predominantly related to the spectral characteristics of coastal biotopes and the spatial resolution limitations of the satellite images used. Table shows a comparison of the automated calculation results and the operational characteristics of water bodies.

The calculation of morphometric parameters of water bodies showed high reproducibility of results. The error in determining the area of a water mirror does

not exceed 6–7%, even for objects with an area of more than 100 square metres. The accuracy of the calculations is highly dependent on the quality of the source data and their spatial resolution. For high-resolution images (less than 5 meters per pixel), the best accuracy is achieved, whereas for images with medium resolution, some errors may occur in the definition of complex shoreline contours.

Comparison of the results of the software package and the actual characteristics of water bodies

Water body	Area from open sources, km²	Area as a result of the software package operation, km²	Relative mean error, %	Processing time, sec
Yamkinskoe Lake	0.098	0.096	2.1	0.4
Chernogolovskoye Reservoir	0.28	0.27	3.6	0.9
Lake Seremo	19.62	20.37	3.7	1.7
Lake Lacha	340	361	6.2	4.3

Source: compiled by A.V. Gusev according to the results of work of the software complex.

The results obtained demonstrate not only the technical efficiency of the algorithms, but also their significant potential for integration into the state monitoring system of water bodies. The development is particularly valuable for solving problems related to the rapid detection of changes in the morphometric characteristics of water bodies — a key parameter in the assessment of anthropogenic effects on aquatic ecosystems. Thus, automated calculation of the coefficient of erosion of the shoreline allows to predict areas of accumulation of pollutants, which is critical in the design of observation networks, including within the development and improvement of FGIS "Eco-monitoring"[1]. Comparison of the data obtained by means of a developed complex with the materials of the "data showcase" of Rosvodresource[2] (in particular, with the dynamic change of the water pollution index WPI) showed a high degree of correlation when analyzing seasonal fluctuations of water quality in test ponds. This confirms that the system can be used to verify official monitoring indicators, especially with regard to the spatial distribution of sampling points. This convergence of data shows that the proposed solution is able not only to duplicate, but also to complement existing methods of observation by taking into account morphodynamic features of a particular water body.

[1] *FGIS «Eco-monitoring»*. Available from: https://ecomonitoring.mnr.gov.ru/public/lists/main (accessed: 21.07.2025).
[2] Open data of the Federal Water Agency. *GIS CP Water.* Available from: https://gis.favr.ru/web/guest/opendata (accessed: 23.07.2025).

The results of the automated design of the monitoring station network deserve special attention. The proposed algorithm takes into account the uniformity of the spatial distribution of sampling points. This makes it possible to significantly increase the representativeness of the data obtained while reducing the number of stations required. The results of the programme complex are shown in Figure 2.
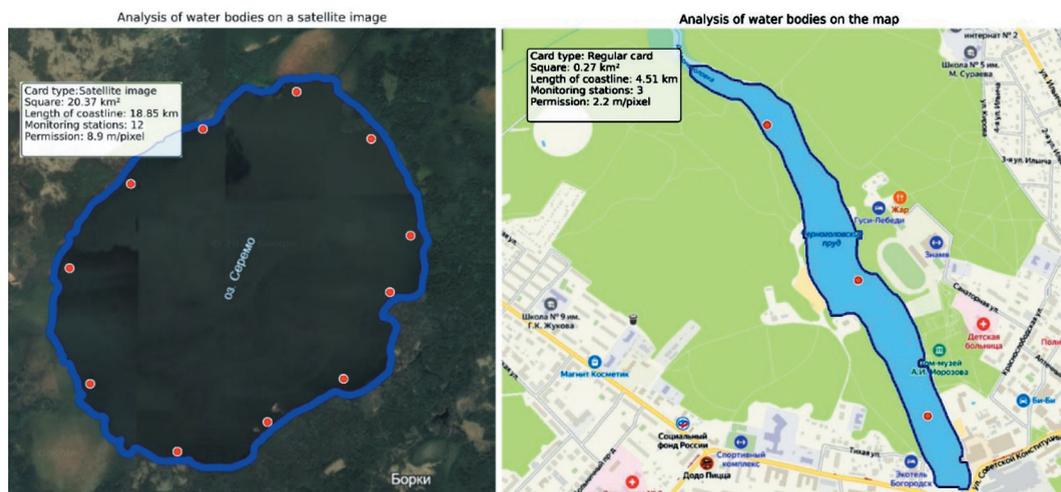

Figure 2. The result of the software package on images of Lake Seremo and the Chernogolovskoye Reservoir
Source: compiled by A.V. Gusev.

Discussion of the results identified several promising areas for further improvement of the system. In particular, the development of mathematical models of current concentration fields based on data from water environmental monitoring stations is of special interest. It is also promising to create algorithms for automatic adaptation of the monitoring network to changing conditions.

Conclusion

The studies carried out have confirmed the effectiveness of the developed software complex to solve the problems of environmental monitoring of water bodies. The main advantage of the proposed approach is that it comprehensively covers all stages of the design of the monitoring network, from processing the original images and classifying them into satellite images and conventional maps to issuing specific recommendations on the location and number of observation stations.

The results show a high degree of automatic determination of key parameters for water bodies. The accuracy of the boundary delineation and the calculation of the motometric characteristics is at a level sufficient to meet most practical environmental monitoring tasks. It is particularly important that the system shows

stable results when working with different types of water bodies and under different natural conditions.

The algorithms developed to optimize the monitoring network significantly improve the organization of observations. The software implementation of these algorithms has shown that it is possible to significantly reduce the number of stations while improving spatial coverage and data representativeness. This provides a good basis for the wider application of the system in environmental monitoring and water management.

The practical importance of the study is to create a tool that can significantly modernize the procedure for collecting primary data for the state monitoring system. The developed system addresses the existing gap between remote sensing technologies and regulatory requirements for observations of water bodies. Its introduction into the practice of hydrological services will allow to take to a new level the solution of such problems as the formation of annual reports "On the state and use of water resources"[3], where the processing of spatially distributed data has traditionally been a particular challenge. The future direction of development of the system is seen as the creation of a module for the automatic formation of reporting map-schemes that meet the requirements of the RD Methodological Instructions 52.24.643-2002[4]. This opens up opportunities for end-to-end automation - from the analysis of satellite images to entering data into a public water register.

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