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Correspondence author
@ O.Y. Pitsun
oleh.pitsun@gmail.com

M. O. Berezkyi, O. Y. Pitsun

West Ukrainian National University, Ternopil, Ukraine

METRICS-BASED IMAGE COMPARISON SOFTWARE MODULE

Developed a software module for automatic image comparison based on classical and advanced distance metrics to enhance the precision of biomedical image analysis. The study addresses the growing demand for intelligent tools capable of quantitative comparison of complex image structures, overcoming the limitations of existing systems such as ImageJ and Axio Vision. The research focuses on integrating Frechet, Hausdorff, Gromov – Frechet, Gromov – Hausdorff, and fuzzy Frechet and Hausdorff metrics within a unified modular architecture designed for distributed data environments. The methods of the research rely on the use of modern programming technologies (Java, PHP, Vue.js, Laravel, MySQL, OpenCV) and the principles of software modularity and service-oriented design.

Investigated the design and implementation of a web-based interface that enables users to upload, preview, and compare images interactively. The architecture integrates a RESTful API, microservice-based communication, and visualization components to represent metric results numerically and graphically. Established a relational database schema including entities for users, studies, comparators, and results, ensuring scalability and data integrity. Developed the core module consisting of the RestClient, MainComparator, and a set of specialized metric classes that implement the Comparator interface, allowing easy extension by new algorithms.

The developed system demonstrates a substantial improvement over existing software by combining traditional and modern metric-based methods and enabling remote interaction and integration with cloud services. Comparative analysis with ImageJ, Axio Vision, and HIAMS systems revealed that the proposed module uniquely supports both Gromov-based and fuzzy metrics while maintaining a user-friendly web interface and REST API access. The results confirmed the efficiency of the designed module for segmentation and clustering of biomedical images and its integration into the “BRECCAD” system for automatic breast cancer diagnosis. The proposed approach enhances reproducibility, modularity, and analytical accuracy, providing a foundation for further development of intelligent diagnostic software.

Keywords: metrics-based image comparison, Fréchet distance, Hausdorff distance, Gromov – Fréchet metric, Gromov – Hausdorff metric, fuzzy metric, software module, biomedical image analysis, RESTful API, web interface.

Introduction

Modern tasks of biomedical image analysis require high precision in comparing microstructures of complex shapes. Traditional software systems, such as ImageJ and Axio Vision, provide basic functions for image preprocessing and segmentation; however, they are limited in their ability to use modern methods for quantitative comparison of graphical objects. Advanced solutions in the HIAMS system integrate individual metrics, in particular the Fréchet and Hausdorff metrics, but they do not provide comprehensiveness and scalability for working with large volumes of data.

In the context of the growing role of computer vision and artificial intelligence systems, there arises a need to create tools that combine classical and modern approaches to calculating distances between images and have extended capabilities for integration with distributed data processing environments. Of particular relevance is the use of Gromov – Fréchet and Gromov – Hausdorff metrics for determining the minimal distance between images. This makes it possible to improve the accuracy of image comparison and classification. In addition, an important direction is the application of fuzzy Fréchet and Hausdorff metrics for comparing images within certain ranges.

Therefore, the development of a software module for image comparison based on these metrics is a relevant and significant task.

Object of the research – development of software systems.

Subject of the research – systems for automatic comparison of graphical objects based on the Fréchet, Hausdorff, Gromov – Fréchet, Gromov – Hausdorff, and fuzzy Fréchet and Hausdorff metrics.

Purpose of the work – to develop a software module for image comparison based on the Fréchet, Hausdorff, Gromov – Fréchet, Gromov – Hausdorff, and fuzzy Fréchet and Hausdorff metrics, which will make it possible to perform image segmentation and clustering.

To achieve the stated purpose, the following main *research tasks* have been defined:

- to analyze scientific works in order to determine the similarity of graphical objects;
- to develop the architecture of the software module;
- to develop the life cycle of the software module operation for comparing two objects based on a microservice architecture with elements of a web interface;

- to implement the module programmatically.

Materials and methods. The research was conducted using modern programming technologies, the theory of algorithms, and the theory of metrics. The article employs the Java and PHP programming languages, the Vue.js framework, the Laravel framework, the OpenCV computer vision library, and the MySQL database.

Analysis of recent research and publications. Article [1] is devoted to the issue of evaluating the quality of medical image segmentation, which is a key stage in medical data processing tasks. The authors emphasize that the comparison of segmentation results requires the use of appropriate metric approaches; however, modern studies face a number of significant challenges. Article [2] highlights a global problem related to the imperfection of machine learning (ML) algorithm validation, particularly in the context of biomedical image analysis. The use of inappropriate metrics leads to results that do not reflect the true needs of the field, which in turn hinders the implementation of ML solutions in practice. Article [3] addresses the problem of image quality assessment (IQA), which is a complex but extremely important task in digital image processing. The authors consider a wide range of both objective reproducibility metrics (for example, MSE, PSNR) and subjective metrics that model the functioning of the human visual system (HVS), among which are UQI, SSIM, FSIM, GSM, and others. Additionally, approaches based on image degradation models, particularly the Noise Quality Measure (NQM), are analyzed. In study [4], new metrics for assessing texture similarity are proposed, which take into account human visual perception and the stochastic nature of textures. The metrics are based solely on local image statistics and allow for significant point deviations between textures that are perceived by humans as essentially identical. The approach extends the concept of structural similarity (SSIM) and relies on research in the field of texture analysis and synthesis. Study [5] examines the process of image fusion, which involves combining a panchromatic (PAN) image of high spatial resolution with a multispectral (MS) image containing rich spectral information into a single composite image. The resulting fusion provides a simultaneous improvement in both spatial and spectral quality compared to the original data. Study [6] addresses the issue of automatic biomedical image analysis and the key role of metrics for objective, transparent, and comparative evaluation of algorithms. Recent research has revealed significant shortcomings in algorithm validation, especially regarding the use of standard metrics. Image quality assessment is a crucial stage in evaluating new hardware, software, image acquisition methods, reconstruction, or post-processing. Over the past decade, numerous IQA methods have been developed for natural images, while their application to medical images has remained limited.

Article [7] summarizes the current advances in the field of medical image quality assessment (IQA), particularly in magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound diagnostics. In study [8], a new database of distorted test images, TID2008, is used to evaluate full-reference image quality metrics. A comparative analysis between TID2008 and its closest counterpart – the LIVE database – was performed. A wide range of well-known metrics was assessed for their correspondence to the perception of the human visual system. Study [9] investigates the correspondence between the L1 and L2 metrics and human perception of image similarity. Experiments involving fragments and recognizable patterns showed a small but consistent advantage of the L1 metric. The results indicate that L1 better reflects human perception of the similarity of natural images.

In study [10], the problem of image segmentation based on a textual query is formulated not as direct prediction of pixel-level masks but as sequential generation of polygons, which can subsequently be converted into segmentation masks. For this purpose, a new sequence-to-sequence architecture called Polygon Transformer (PolyFormer) is proposed. It takes as input a sequence of image patches and textual query tokens and autoregressively generates polygon vertices as output. In article [11], an Adaptive Polygon Generation Algorithm (APGA) for automatic building extraction is proposed, which aims at the direct formation of a polygonal contour as a sequence of vertices describing each building object. Unlike traditional segmentation methods, APGA predicts the positions of vertices and determines their ordering, taking into account the position and orientation of the building boundary.

In the review study [12], detailed instructional materials are presented regarding two classical methods of polygonal computer-generated holography: the traditional method (based on the Fast Fourier Transform) and the analytical method, which form the foundation for modern approaches.

In the systematic review [13], the role of competent software architecture in solving complex big data processing tasks for SQL and NoSQL databases is examined. SQL databases provide data organization and horizontal scalability, while NoSQL databases support efficient processing of large volumes of unstructured data with high scalability. Study [14] emphasizes the critical role of software architectures in ensuring the quality of software-intensive systems. Reference architectures abstract key software elements, define core responsibilities and interactions within a domain, and guide the architectural design of new systems, providing improved compatibility, reduced costs through reuse, decreased project risks, and enhanced communication.

The Fréchet metric and its modifications are described in studies [15–17].

Research results and their discussion

User interaction interface

The developed web page is an interactive interface designed to demonstrate the process of comparing two images using metrics. Its structure includes several functional blocks, each performing a specific role in the overall logic of user interaction with the system.

At the top of the page, there is a header that identifies the purpose of the resource, as well as a navigation menu with two tabs: "Home" and "Metrics". This provides basic user orientation within the interface.

The developed web interface is shown in Fig. 1.

The main part of the page consists of two symmetrical blocks for uploading images. Each block contains a file input element, an image preview area, and a metadata section. The metadata include the file name, its MIME type, and size in bytes, allowing the user to obtain basic information about the uploaded object. The input parameters for these blocks are the image files that the user selects locally.

After both images are uploaded, a comparison button becomes active, which initiates the generation of conditional numerical values for six metrics: Fréchet, Gromov – Fréchet, Hausdorff, Gromov – Hausdorff, fuzzy Fréchet metric, and fuzzy Hausdorff metric.

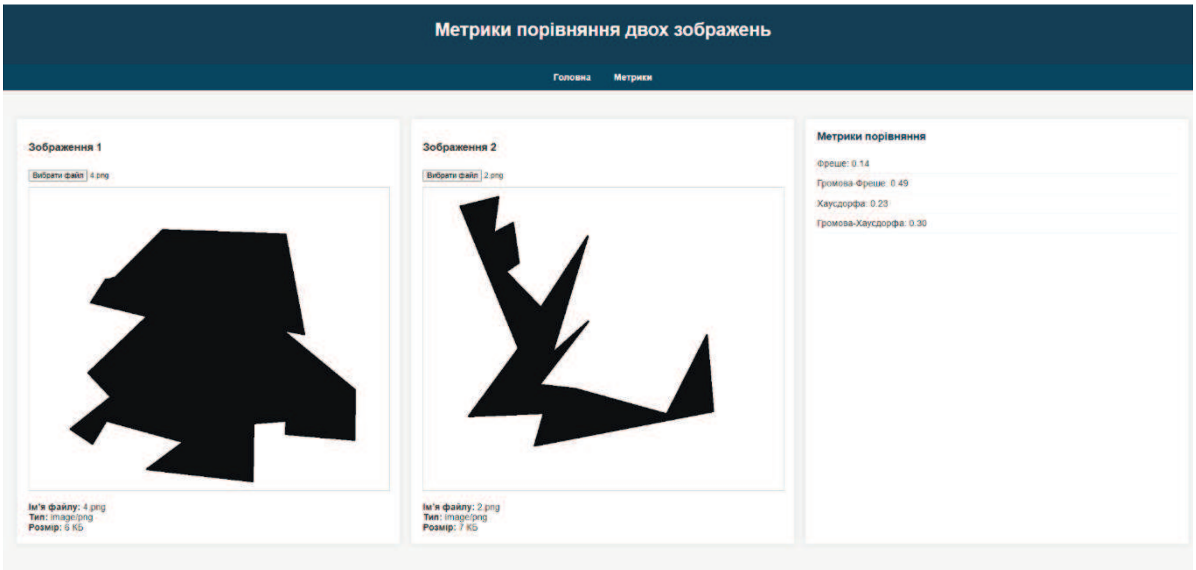

Fig. 1. Image input and visualization block

The output of the metrics is implemented as a list and also graphically – using a bar chart built on the Chart.js library. The input parameters for this block are the numerical metric values obtained as a result of the simulation.

Sequence diagram

The sequence diagram of the operation of the web interface is shown in Fig. 2.

Within the implemented web interface for image comparison, the sequence of user actions and the corresponding system responses form a logically complete interaction scenario that encompasses data uploading, processing, result visualization, and access management to service parameters. A step-by-step description of this process is provided below in a scientific style.

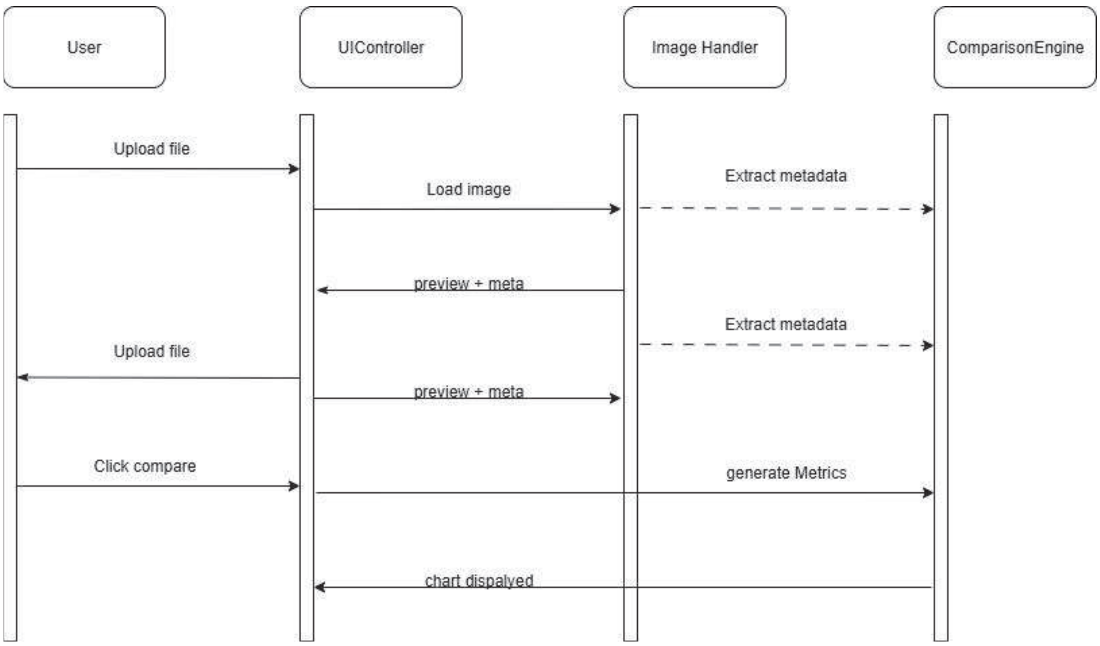

Fig. 2. Sequence diagram

At the initial stage, the user uploads the first image through a file input element. In response to this action, the client side of the interface initiates a file processing function that includes creating a local URL object for preview and extracting basic metadata such as file name, MIME type, and size in bytes. A similar procedure is repeated for the second image, ensuring symmetrical preparation of input data for further comparison.

Database

The ER diagram of the database is shown in Fig. 3.

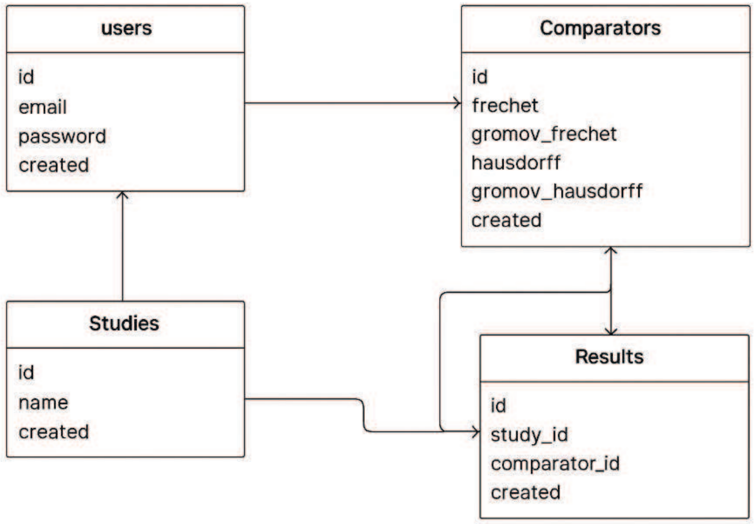

Fig. 3. ER diagram of the database

The diagram includes four main tables – *Users*, *Researches*, *Results*, and *Comparators*. The presented database diagram models the structure of an information system designed for storing and processing image comparison results. It is implemented as a relational schema that includes four main entities: users (*Users*), comparators (*Comparators*), studies (*Studies*), and results (*Results*). Each table contains a set of attributes that ensure the storage of relevant data, as well as established inter-table relationships that define the logic of interaction between system objects.

The requirements for the server part of the database are presented in Table 1.

Structure of the software module

The developed software system is based on a modular approach and provides for the integration of tools for comparing geometric objects with mechanisms for interaction with remote services via a RESTful API. The structure of the software module is shown in Fig. 4.

Table 1. Database requirements

Operating system	Database server	Recommended amount of disk space	Ability to use distributed databases
Windows/Linux/ MacOS	MySQL	1 Gb	+

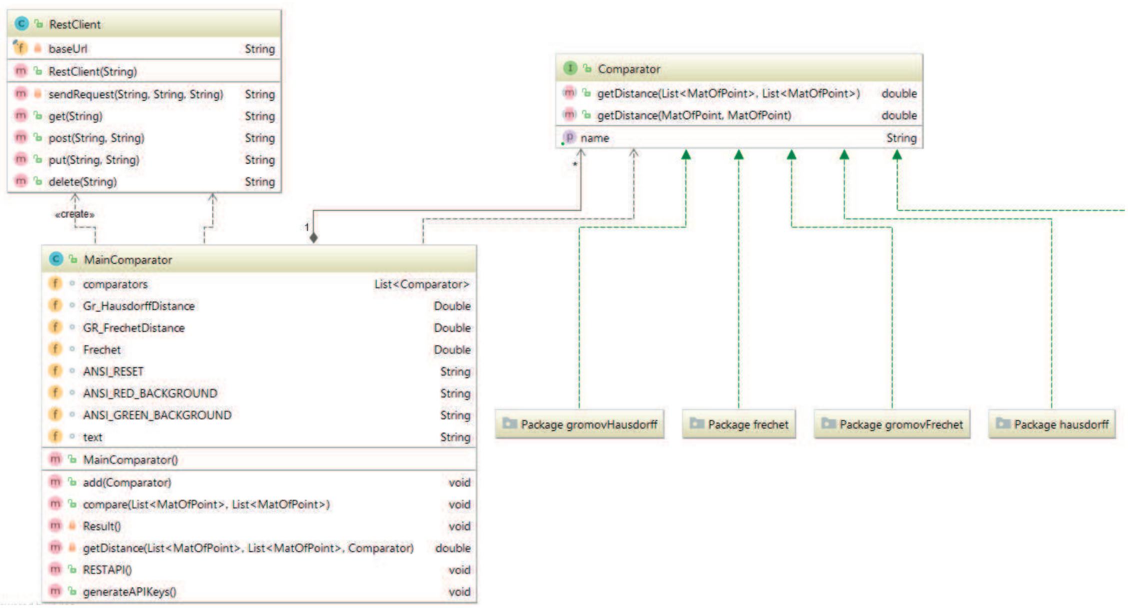

Fig. 4. Structure of the software module

The main components of the system are as follows:

The *RestClient* class performs the functions of a client for the RESTful API and provides unified handling of HTTP requests. The class contains the base server address (*baseUrl*) and methods for sending different types of requests (GET, POST, PUT, DELETE). The universal method *sendRequest* encapsulates the logic of request formation, message body transmission, and server response processing. This module is used by other components to access external resources.

The *Comparator* interface defines a contract for algorithms that compare geometric structures. The interface includes *getDistance* methods that implement the calculation of distances between individual contours (*MatOfPoint*) or between sets of contours. Such generalization allows the system to be extended by adding new algorithms without modifying the main code.

The *MainComparator* class is the central module of the system that manages the set of comparators. It stores a collection of objects implementing the *Comparator* interface and provides methods for adding new algorithms, performing comparisons, and obtaining calculation results. In addition, the class implements methods for integration with the RESTful API (*RESTAPI*) and for generating API keys for authentication. Auxiliary fields of the class (*ANSI_RESET*, *ANSI_RED_BACKGROUND*, *ANSI_GREEN_BACKGROUND*) are used for visualization of results in the console interface.

Specialized packages implement specific variants of comparison algorithms based on different metrics (Hausdorff, Fréchet, etc.). Each of these modules inherits the *Comparator* interface, ensuring a unified mechanism of integration into the system.

Thus, the developed architecture combines the flexibility of using various comparison algorithms with the ability to interact with external services. Owing to the interface-oriented approach, the system's extensibility is ensured, and the use of a separate client module (*RestClient*) guarantees independence from a particular implementation of the data transfer protocol.

Discussion of the research results. To evaluate the effectiveness of the developed module, a comparative analysis was carried out with well-known systems for digital image processing and analysis, including ImageJ, Axio Vision, and HIAMS. All the considered software solutions provide basic capabilities for image preprocessing and segmentation. However, only the HIAMS system implements support for the Fréchet and Hausdorff metrics, while ImageJ and Axio Vision lack these tools. The proposed module, unlike existing analogues, combines the use of classical metrics (Fréchet, Hausdorff) with the implementation of advanced approaches, including the Gromov – Fréchet, Gromov – Hausdorff, fuzzy Fréchet, and fuzzy Hausdorff metrics, which significantly increase the accuracy of geometric structure analysis.

In addition, the developed module has integrated tools for interaction with remote services through a REST API and provides access via a web interface, making it suitable for scalable and distributed data processing systems. Thus, compared to known solutions, the proposed architecture offers a wider range of analytical capabilities and better integration with modern infrastructural technologies.

Table 2 presents a comparison of the developed module with existing solutions.

Table 2. Comparison of the developed module with existing solutions

Criterion	ImageJ	Axio Vision	HIAMS	Developed module
Preprocessing	+	+	+	+
Segmentation	+	+	+	+
Fréchet metric	–	–	+	+
Gromov – Fréchet metric	–	–	–	+
Hausdorff metric	–	–	+	+
Gromov – Hausdorff metric	–	–	–	+
Web interface	–	–	–	+
Rest API	–	–	–	+

The integration of the specialized *RestClient* enables scalable interaction with external data sources and services, expanding the applied capabilities of the developed system. Thus, the resulting architecture is flexible, modular, and oriented toward practical application in tasks of automated analysis and classification of complex-structure objects.

Scientific novelty of the obtained research results – lies in the further development of methods for automatic determination of image similarity through the creation of a comprehensive software system using modern technologies based on the Hausdorff and Fréchet metrics and their modifications.

Practical significance of the obtained results. The main practically significant results of the research were obtained through the combination of theoretical approaches and the applied implementation of image comparison. The developed approaches and architectural solutions are aimed at increasing the efficiency of software tools for automatic image comparison based on metrics.

Conclusions

In this work, an architectural model of a system for comparing geometric objects has been developed, combining an interface-oriented approach to algorithm implementation and tools for integration with remote services via RESTful API.

The developed module provides the capability to use various metrics (Hausdorff, Fréchet, and their modifications) and supports extensibility by adding new comparators without modifying the core modules.

The developed module, which calculates distances between micro-objects in biomedical images, is part of the computer program "BRECCAD" designed for the automatic diagnosis of breast cancer and its subtypes.

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М. О. Березький, О. Й. Піцун

Західноукраїнський національний університет, м. Тернопіль, Україна

ПРОГРАМНИЙ МОДУЛЬ ПОРІВНЯННЯ ЗОБРАЖЕНЬ НА ОСНОВІ МЕТРИК

Розроблено програмний модуль для автоматичного порівняння зображень на основі класичних і сучасних метрик відстані з метою підвищення точності аналізу біомедичних зображень. У роботі розглянуто дедалі більшу потребу в інтелектуальних інструментах, придатних для кількісного порівняння складних структур зображень, що долає обмеження таких систем, як ImageJ і Axio Vision. Дослідження зосереджене на інтеграції метрик Фреше, Хаусдорфа, Громова – Фреше, Громова – Хаусдорфа, а також нечітких метрик Фреше й Хаусдорфа в єдиній модульній архітектурі, призначеній для розподілених середовищ оброблення даних. Методи дослідження ґрунтуються на використанні сучасних технологій програмування (Java, PHP, Vue.js, Laravel, MySQL, OpenCV) та принципів модульності й сервісно-орієнтованого проєктування.

Досліджено розроблення та реалізацію вебінтерфейсу, який дає змогу користувачам інтерактивно завантажувати, переглядати та порівнювати зображення. Архітектура інтегрує RESTful API, мікросервісну комунікацію та засоби візуалізації для відображення результатів метрик у числовому та графічному вигляді. Визначено реляційну схему бази даних із сутностями для користувачів, досліджень, компараторів і результатів, що забезпечує масштабованість і цілісність даних. Розроблено основний модуль, який складається із компонентів RestClient, MainComparator та набору спеціалізованих класів метрик, що реалізують інтерфейс Comparator, забезпечуючи просте розширення системи новими алгоритмами.

Розроблена система демонструє істотне вдосконалення порівняно з наявним програмним забезпеченням, поєднуючи традиційні та сучасні методи на основі метрик і забезпечуючи віддалену взаємодію та інтеграцію з хмарними сервісами. Порівняльний аналіз із системами ImageJ, Axio Vision та HIAMS показав, що запропонований модуль унікально підтримує метрики на основі Громова та нечіткі метрики, одночасно надаючи зручний вебінтерфейс і доступ через REST API. Результати підтвердили ефективність модуля для задач сегментації та кластеризації біомедичних зображень і його інтеграцію у систему “BRECCAD” для автоматичного діагностування раку молочної залози. Запропонований підхід підвищує відтворюваність, модульність і точність аналізу, створюючи основу для подальшого розвитку інтелектуальних діагностичних систем.

Ключові слова: програмний модуль, метрика Фреше, метрика Хаусдорфа, метрика Громова – Фреше, метрика Громова – Хаусдорфа, нечітка метрика Фреше, нечітка метрика Гаусдорфа.

Інформація про авторів:

Березький Микола Олегович, аспірант, кафедра комп’ютерної інженерії.

Email: mykolaberezkyy@gmail.com; https://orcid.org/0000-0001-6507-9117

Піцун Олег Йосипович, канд. техн. наук, доцент, кафедра комп’ютерної інженерії.

Email: oleh.pitsun@gmail.com; https://orcid.org/0000-0003-0280-8786

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