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USE OF GRADATION CORRECTION METHOD FOR IMPROVING THE VISUALIZATION OF COMPUTED TOMOGRAPHY RESULTS

The aim of this work is to improve the quality of visualization of computed tomography (CT) results by enhancing digital image processing methods based on gradation correction. The proposed approach employs an adaptive brightness transformation model with the possibility of expert parameter tuning and their subsequent scaling according to the characteristics of a specific CT image. The research methodology is based on the analysis of the statistical distribution of pixel intensities and the controlled truncation of non-informative histogram tails. Gradation correction parameters may be defined as predefined expert settings or adjusted by the user in an interactive mode, which enables the adaptation of visualization to various clinical scenarios and analysis tasks.Experimental studies on CT images containing metallic and non-metallic objects demonstrated that the application of the proposed approach reduces the influence of glare effects and local overexposures typical of standard viewing modes. In particular, for metallic fragments, where standard visualization resulted in an overestimation of linear dimensions by up to 50%, the use of adaptive gradation correction with truncation of non-informative histogram tails reduced the measurement error to approximately 15% and improved visual perception. This ensures a more accurate representation of the geometric parameters of objects without loss of diagnostically significant information.The scientific novelty of the work lies in the improved application of the gradation correction method for computed tomography tasks through the combination of expert-driven parameter control with adaptive scaling of the intensity range. The practical significance of the study lies in the possibility of integrating the proposed approach into software systems for viewing and preprocessing CT images, which meets the real needs of radiologists and surgeons and contributes to improving the accuracy of visual assessment of CT examination results.
Keywords: computed tomography, gradation correction method, image processing, computer vision, contrast enhancement, software.

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ВИКОРИСТАННЯ МЕТОДУ ГРАДАЦІЙНОЇ КОРЕКЦІЇ ДЛЯ ПОКРАЩЕННЯ ВІЗУАЛІЗАЦІЇ РЕЗУЛЬТАТІВ КОМП'ЮТЕРНОЇ ТОМОГРАФІЇ

Метою даної роботи є підвищення якості візуалізації результатів комп'ютерної томографії шляхом удосконалення методів цифрової обробки зображень на основі градаційної корекції. Запропонований підхід передбачає використання адаптивної моделі перетворення яскравості з можливістю експертного налаштування параметрів та їх подальшого масштабування відповідно до характеристик конкретного КТ-зображення. Методика дослідження базується на аналізі статистичного розподілу інтенсивностей пікселів та керованому відсіканні неінформативних хвостових ділянок гістограми. Параметри градаційної корекції можуть задаватися у вигляді попередньо визначених експертних налаштувань або змінюватися користувачем у інтерактивному режимі, що дозволяє адаптувати візуалізацію до різних клінічних сценаріїв і задач аналізу. Експериментальні дослідження на КТ-зображеннях із металевими та неметалевими об'єктами показали, що застосування запропонованого підходу зменшує вплив ефекту «блиску» та локальних пересвічувань, характерних для стандартних режимів перегляду. Зокрема, для металевих фрагментів, у яких за умов стандартної візуалізації спостерігалося завищення лінійних розмірів до 50%, використання адаптивної градаційної корекції з відсіканням неінформативних хвостів дозволило знизити похибку вимірювань до 15% та поліпшити візуальне сприйняття.. Це забезпечує більш коректне відображення геометричних параметрів об'єктів без втрати діагностично значущої інформації. Наукова новизна роботи полягає в удосконаленні застосування методу градаційної корекції для задач комп'ютерної томографії шляхом поєднання експертного керування параметрами з адаптивним масштабуванням діапазону інтенсивностей. Практична значимість дослідження полягає у можливості інтеграції запропонованого підходу в програмні системи перегляду та попередньої обробки КТ-зображень, що відповідає реальним потребам рентгенологів і хірургів та сприяє підвищенню точності візуальної оцінки результатів КТ-досліджень.
Ключові слова: комп'ютерна томографія, метод градаційної корекції, обробка зображень, комп'ютерний зір, покращення контрасту, програмне забезпечення.

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Introduction

The problem of improving digital image quality remains one of the key challenges in modern information technologies. Data visualization plays a central role in contemporary IT systems, particularly in the fields of analysis, modeling, and medical diagnostics. The quality of visual representation directly affects the effectiveness of subsequent image processing, the accuracy of object recognition, and the reliability of clinical and analytical decisions. This issue is especially critical in medicine, where medical images often serve as the primary or sole source of diagnostic information. Computed tomography (CT) provides a layered representation of internal anatomical structures with high spatial resolution; however, CT images frequently contain noise, reconstruction artifacts, or insufficient contrast, which complicates their interpretation by clinicians and software-based analysis systems [1].

The need to improve the visualization quality of CT images is driven by several factors. First, during scanning, significant variations in brightness levels occur due to the physical properties of tissues, imaging protocols, and technical characteristics of the tomographic equipment. Second, CT images often include regions with extremely low or excessively high intensity values that carry little diagnostic value but negatively affect overall image perception. As a result, at the preprocessing stage arises the task of enhancing contrast and improving the visual separation of diagnostically significant structures.

One of the widely used approaches for addressing this task is the gradation correction method, which is based on nonlinear transformations of pixel intensity values. By modifying the brightness transfer function, it becomes possible to emphasize subtle intensity differences and enhance contrast in selected regions of interest. Traditional gradation correction techniques typically operate within a fixed intensity range of 0–255, which is not always optimal for medical images, where diagnostically relevant information may be concentrated within a narrower or unevenly distributed intensity interval.

Therefore, an important direction in CT image processing is the refinement of gradation correction techniques through adaptive adjustment of brightness transformations in accordance with image characteristics and clinical objectives. Flexible control of the effective intensity range, including the suppression of non-informative extreme values, enables improved visual clarity of anatomical boundaries and pathological formations without loss of diagnostically significant information. Such approaches enhance not only human visual perception but also create more favorable conditions for subsequent segmentation, measurement, and analysis tasks.

Thus, the development and improvement of digital image processing methods, particularly those based on adaptive gradation correction with expert-controlled parameter tuning, constitute an essential means of increasing the efficiency of medical image visualization software. This contributes to more reliable visual assessment of CT data and supports the development of decision-support tools in clinical practice.

State-of-art

Today, a wide range of commercial and freely available software tools is used for visualization and initial processing of computed tomography (CT) images. Among the most common solutions are RadiAnt DICOM Viewer, 3D Slicer, OsiriX, as well as proprietary console software supplied by CT scanner manufacturers such as Siemens, GE, and Philips. These systems typically provide basic functionality for adjusting image brightness and contrast through window level and window width parameters, allowing clinicians to adapt visualization to a specific anatomical region or diagnostic task. In most cases, such adjustments are performed manually or in a semi-interactive manner [2,3].

Beyond classical manual windowing, several approaches to contrast enhancement of medical images have been proposed in the literature. One widely studied group of methods includes local histogram-based techniques, such as histogram equalization and its constrained variants, most notably Contrast Limited Adaptive Histogram Equalization (CLAHE). These methods are capable of enhancing local contrast and improving the visibility of fine details in X-ray and CT images. However, their application in clinical CT visualization is limited by several factors, including increased computational complexity, amplification of image noise, and distortion of intensity distributions. As a result, such methods may negatively affect quantitative interpretation and are not commonly used in routine clinical viewing workflows [4–6].

Another active research direction involves the application of artificial intelligence, particularly deep learning, to the problem of CT image visualization. Recent studies explore automatic or learned adjustment of windowing parameters, including auto-windowing strategies based on image statistics or task-specific objectives such as segmentation or classification. In some cases, windowing operations are embedded directly into neural network architectures as learnable or interpretable layers [7–9]. While these approaches demonstrate promising results in controlled experimental settings, they often require large annotated datasets, significant computational resources, and complex training procedures. Consequently, such solutions are primarily used in research contexts and are rarely integrated into everyday clinical visualization tools.

Despite the diversity of existing methods, practical non-neural approaches suitable for routine CT visualization remain relatively limited. In particular, the problem of adaptively selecting an informative intensity range while preserving diagnostically relevant structures is most often addressed using fixed percentile thresholds or empirically chosen parameters. These solutions lack flexibility and may perform inconsistently across different scanning conditions, object densities, and anatomical regions [10,11].

Furthermore, most modern visualization systems rely almost exclusively on manual parameter adjustment, and the results of expert tuning are not formalized in a reusable form. At the same time, fully automatic solutions are often insufficiently transparent or controllable from the clinician's perspective. This highlights the need for intermediate, hybrid approaches that combine expert-driven parameter selection with adaptive application mechanisms, ensuring both flexibility and reproducibility of visualization results [12].

Thus, although numerous tools and methods for CT image visualization exist, there remains a gap between theoretical contrast enhancement techniques and practically applicable solutions suitable for routine clinical use. In particular, the lack of adaptable, expert-oriented gradation correction methods that improve visualization quality without introducing excessive computational complexity or altering diagnostic content motivates the development of the approach proposed in this work.

Purpose

The purpose of this article is to improve the quality of visualization of computed tomography (CT) results by enhancing the process of image gradation correction. The main focus is on automating the selection of the informative intensity range, which allows increasing the contrast of important image regions without losing diagnostic information. This, in turn, contributes to a more accurate delineation of anatomical structures and pathological formations during the initial review of tomograms.

The aim of this work is to develop a method that combines the advantages of expert parameter tuning with the ability to automatically apply these parameters to new images. Such an approach minimizes the influence of the human factor and ensures result reproducibility in standard clinical scenarios.

Another goal is to create an efficient algorithm for constructing a tabular brightness transformation function based on a truncated histogram, which enables fast data processing without significant computational load. This is particularly important for integration into practical DICOM image viewing systems, where processing speed is a critical factor.

Thus, the article presents a solution aimed at improving the efficiency and accuracy of CT image preprocessing, creating a foundation for the further integration of automated gradation correction methods into clinical software and diagnostic decision-support systems.

Proposed technique

For high-quality analysis of computed tomography results, efficient visualization of CT data in the DICOM format is required, with emphasis on diagnostically significant structures across a wide range of densities. In this work, a unified exponential–logarithmic gradation correction model is used, which combines linear, exponential, and logarithmic brightness transformations

$$F_{el}(\lambda, x) = \begin{cases} \lfloor Z1 \rfloor \; if \; 0 \le \lambda \le 1, \\ \lfloor Z2 \rfloor \; if \; 1 \le \lambda \le 2, \\ \quad 0 \le \lambda \le 2, \end{cases} \tag{1}$$

where the parameters Z1 and Z2 are determined as

$$\begin{cases} Z1 = (1-\lambda)\cdot ef(x) + [1-(1-\lambda)]\cdot p(x), \\ Z2 = [1-(\lambda-1)]\cdot p(x) + (\lambda-1)\cdot 1f(x), \end{cases} \tag{2}$$

$\lfloor\cdot\rfloor$– denotes the rounding operator, with $F_{el}(\lambda, x) \in [c, \dots, d]$.

Here x – is the input density value, $x \in [a, \dots, b]$; the coefficient $\lambda, 0 \le \lambda \le 2$, defines the contribution of the basic functions p(x), ef(x), 1f(x) to the resulting brightness value in equations (1) and (2).

The transformation values in (1) and (2) are computed using the following base family of correction functions:

$$p(x) = k\cdot(x-a) + c, \; k = \frac{d-c}{b-a} \tag{3}$$

$$ef(x) = (e^k - 1) + c, \; k = \frac{\ln(d-c+1)(x-a)}{b-a} \tag{4}$$

$$1f(x) = \frac{d-c}{\ln(b-a+1)}\cdot \ln(x-a+1) + c \tag{5}$$

The model (1)–(5) was chosen because it provides an efficient solution to most practical problems of gradation correction. It is unified with respect to data representation models and automatically adapts to the actual density range [a,…,b] and brightness range [c,…,d].

The linear component preserves proportional relationships between intensity levels, the exponential component enhances contrast in low-intensity regions typical for soft tissues, and the logarithmic component limits saturation in high-density areas such as bone structures or metallic inclusions. This combination reflects the nonlinear characteristics of human visual perception and corresponds to the practical windowing adjustments routinely performed by radiologists. Unlike classical gamma correction, which represents a single-form nonlinear transformation, the proposed model provides greater flexibility in contrast control across different intensity ranges and employs interpretable parameters, enabling stable and clinically applicable visualization of CT images.

At the parameter-adjustment stage, it is sufficient to specify the coefficient λ. By varying λ, the model flexibly controls the contribution of the base functions (3) – (5) to the resulting brightness (1), providing an adaptive response to the characteristics of each image. Parameter λ is an interactive visualization control that allows specialists to flexibly adjust gradation correction modes depending on the clinical task, without modifying the underlying image data.

An important additional advantage of the model (1) is the ability to apply a criterion for selecting an informative density range within [a,…,b] before performing the gradation correction. This is achieved by cutting off the non-informative tails of the input image's density histogram. Under conditions of poor visibility or low contrast, such truncation leads to a significant (2–4) narrowing of the initial density range and a proportional stretching of the resulting brightness range. The outcome is a corresponding improvement in the visibility and sharpness of objects and tissues in the CT image.

1) Insignificant histogram frequencies h below a threshold T, (h < T) are set to zero(T may be specified by an expert for a particular material or calculated as a percentage of the maximum density of the target object. In one operating mode, non-informative histogram tails corresponding to air and surrounding soft tissues are excluded from the intensity range, as these regions do not contain diagnostically relevant information. In another mode, depending on the maximum density of the object, high-intensity ranges associated with the metal-induced glare and overexposure effects may be selectively truncated. In both cases, the threshold values were determined experimentally and depend on the physical properties and density characteristics of the analyzed object);

2) Histogram frequencies are then normalized so that $\sum h_i = 1$;

3) The new limits [a,…,b] are determined by the outermost non-zero frequencies of the density histogram.

The described model (1) and the associated criterion were used by the authors as the component of an information technology (IT) system for effective visualization of CT images, primarily aimed at estimating the dimensions of foreign objects in the human body.

The developed solution is implemented as part of a broader decision support system (DSS) for medical image analysis. In addition to the gradation correction module, the system includes an automatic module for estimating the geometric dimensions of detected fragments based on processed CT data, as well as a higher-level DSS module responsible for organizing the analysis workflow and supporting clinical decision-making.

The gradation correction and automatic fragment size estimation modules were implemented in C#, ensuring efficient processing of tomographic data, while the graphical interface and the decision support system logic were implemented in Python. The entire system was used for modeling, computational experiments, and comparative analysis of the obtained results.

Results

To verify the effectiveness of the developed method and to assess its suitability for practical use, two experimental studies using computed tomography (CT) were conducted. Both experiments aimed to evaluate the proposed system's ability to improve the accuracy of dimensional estimation and enhance the visualization of three-dimensional objects of various types.

The first experiment focused on the processing of CT images containing metallic fragments. For this purpose, a dataset was created consisting of 24 sets, each containing three fragments, for a total of 72 samples. The dataset included six types of metallic materials: copper and aluminum wire, thin and thick steel nails, as well as two additional types of metallic fragments with differing geometric characteristics. Before the experiments, all samples were photographed, described, manually measured by experts, and documented for subsequent identification[13].

The metallic fragments were placed inside the internal organs of a pig-specifically, the liver, lungs with trachea, and intestines. The selection of these organs was based on their anatomical similarity to human organs and their high diagnostic significance in clinical imaging practice. The placement was performed according to a predefined scheme that involved local grouping of fragments in sets of three with random orientation. This approach ensured reproducibility and allowed for accurate comparison of CT images with expert measurements(Fig.1).

The second experiment aimed to evaluate the method's performance on non-metallic materials, which have densities close to biological tissues and can be difficult to identify in CT imaging. Twelve samples were prepared from three materials - skin, plastic, and rubber, with four objects of different shapes and sizes for each material type. These samples were placed into specially prepared porous foam blocks and muscle tissue to simulate heterogeneous biological environments, followed by tomographic scanning. This approach allowed the assessment of the effectiveness of the gradation correction algorithms for low-contrast structures and helped determine the applicability limits of the developed model in cases of minimal density difference between the object and surrounding materials(Fig.2).

A comparative analysis of the results demonstrated that the use of the improved gradation correction method provides a noticeable enhancement in the visualization of both metallic and non-metallic objects in CT images without distorting diagnostically important information. For metallic fragments, a significant increase in contrast and contour clarity was observed, accompanied by the elimination of local overexposures. For non-metallic samples, the method achieved improved visibility of low-contrast details, which is critically important for practical diagnostics. The obtained data confirmed the effectiveness of the developed algorithm for both high-density and low-density objects embedded within biological tissues.

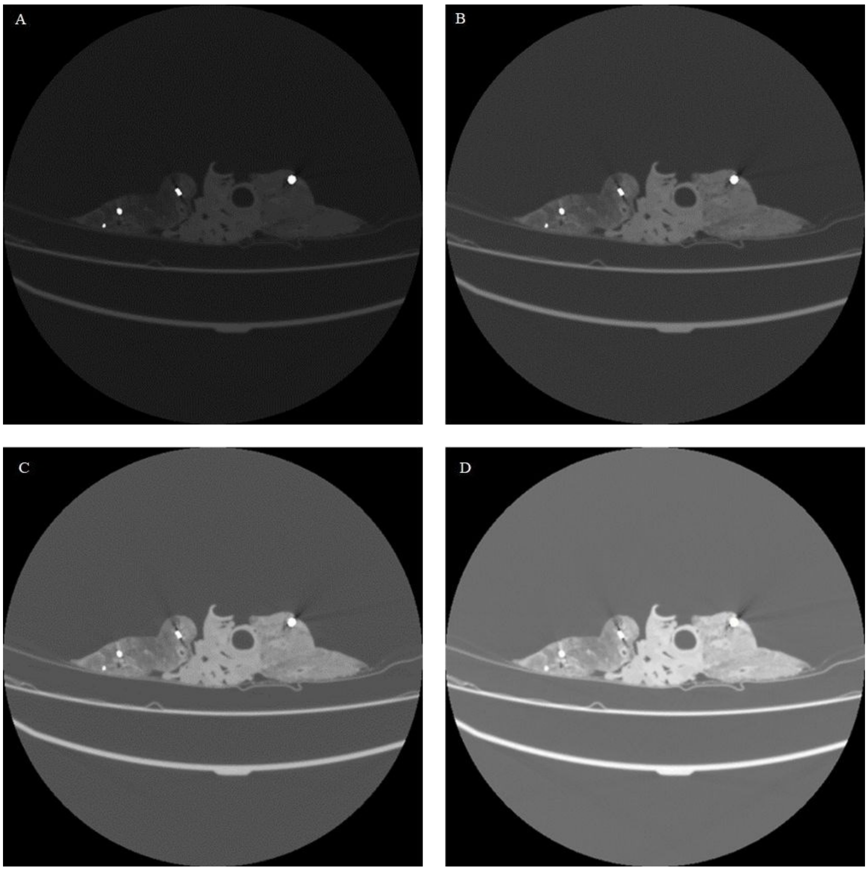

Fig.1 Visualization of the results of CT examination of metallic fragments placed in a pig lung using the proposed software in different viewing modes($\lambda = 0.5(A), 0.75(B), 1(C, linear\ function\ ), 1.25(D)$).

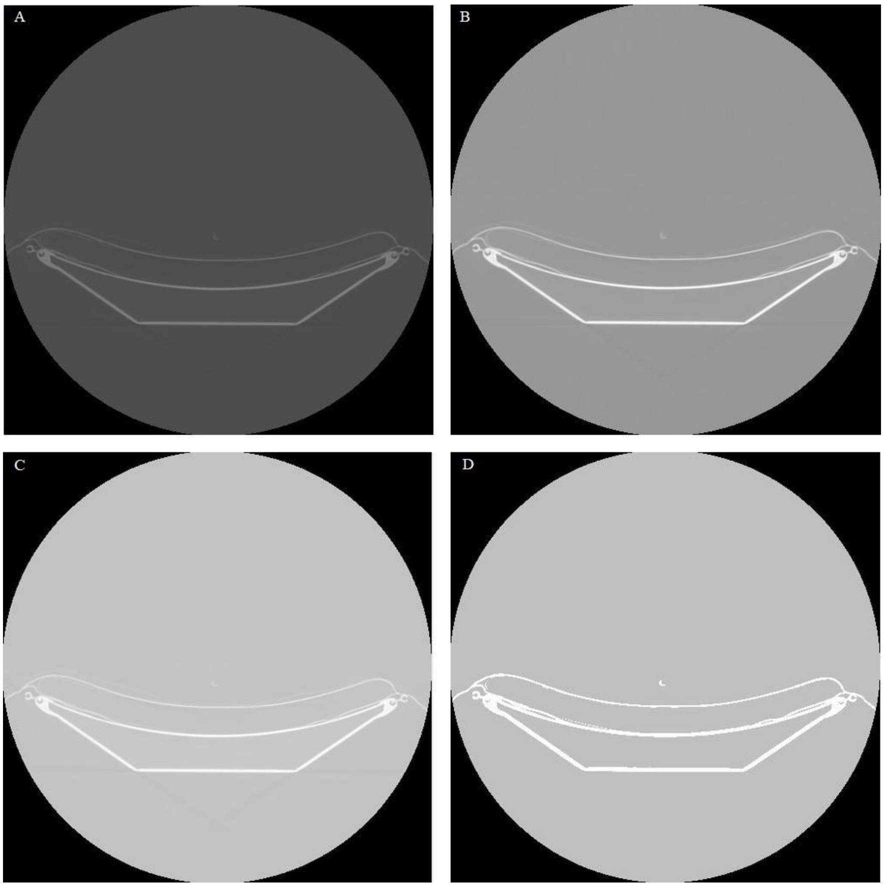

Fig.2 Visualization of the results of CT examination of a plastic sample in a foam block using the proposed software in different viewing modes($\lambda = 0.5(A), 0.75(B), 1(C, linear\ function\ ), 1.25(D)$).

Discussion

The proposed approach should primarily be considered in the context of applied clinical visualization rather than as a purely theoretical image enhancement method. In real-world CT workflows, radiologists and surgeons typically rely on fast, interpretable, and controllable tools. Many well-known enhancement techniques, including CLAHE and its variants, although effective in controlled experiments, are often difficult to use in routine practice due to excessive local contrast amplification, sensitivity to noise, and limited predictability of visual results. For these reasons, such methods are more frequently discussed in academic studies than implemented in daily clinical environments.

The method presented in this work is focused on improving visual interpretability through controlled gradation correction while preserving the familiar paradigm of window-based visualization. Its main limitations lie in cases with extremely strong artifacts, such as severe metal-induced distortions, and in situations where multiple objects of different densities and maximum values are present in the same scan. At the same time, compared to neural network-based solutions, the proposed method does not require training data, large computational resources, or model validation, which makes it more transparent and reproducible for practical use. Thus, the approach occupies an intermediate position between manual windowing and complex AI-based systems, addressing applied visualization needs while maintaining simplicity and robustness.

An important direction for future work is the extension of the method to CT scans containing multiple objects with different density characteristics within a single dataset.

Conclusions

As a result of the conducted research, an improved method of gradation correction for enhancing the visualization of computed tomography (CT) results has been developed and tested. The proposed approach is based on adaptive transformation of pixel intensity values using a unified exponential-logarithmic model, combined with selective exclusion of non-informative intensity ranges. Low-intensity regions corresponding to air and background tissues may be excluded during preprocessing, as well as high-intensity ranges associated with overexposure and glare effects in dense objects, while the final visualization parameters are adjusted by a medical expert according to the diagnostic task.

Experimental evaluation on CT datasets containing objects of different densities demonstrated that the proposed method improves visual clarity and interpretability of tomographic images. In cases involving high-density materials, such as metallic fragments, standard visualization techniques may lead to a significant visual overestimation of object dimensions due to glare and saturation effects. Application of the proposed gradation correction reduced this visual distortion from values reaching approximately 50 percent to about 15 percent by selectively excluding non-informative intensity ranges, including histogram tails corresponding to air, background tissues, and high-intensity regions associated with metal-induced glare and overexposure. For low-density structures, including soft tissues and non-metallic materials, the method enhances contrast and boundary visibility while suppressing irrelevant intensity contributions, without introducing excessive noise or artificial contrast.

The scientific novelty of the obtained results lies in the application of a unified gradation correction model that combines nonlinear brightness transformation with expert-guided parameter adjustment and partial preprocessing of the intensity histogram. This approach provides stable and reproducible visualization results across different CT datasets while preserving diagnostically significant information.

The practical significance of the proposed method lies in its suitability for integration into software systems for viewing and preprocessing CT images. The approach supports flexible expert interaction, improves the consistency of visual assessment, and can be applied in routine clinical practice without substantial computational overhead.

Future research may focus on the development of hybrid visualization modes that combine expert-defined presets with limited adaptive mechanisms, as well as on extending the method to other modalities of medical imaging.

Author Contributions

Conceptualization, K.S. and E.V.; methodology, K.S.; software, E.V.; validation, E.V. and K.S.; formal analysis, K.S.; investigation, E.V.; resources, K.S.; data curation, E.V.; writing - original draft preparation, E.V.; writing - review and editing, E.V. and K.S.; visualization, E.V.; supervision, K.S.; project administration, K.S. All authors have read and agreed to the published version of the manuscript.

Declaration on the use of generative artificial intelligence tools

In preparing this manuscript, the authors used generative artificial intelligence tools (ChatGPT) in a limited manner to assist with language refinement and translation of individual sentences into English. The AI tools were used solely to improve grammar, clarity, and wording consistency. All scientific content, structure, interpretations, and conclusions were developed by the human authors. After using the AI tool, the authors critically reviewed, edited, and validated all text and take full responsibility for the content of this publication.

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