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The Comparative Analysis of Methods for Filtering Medical CT Images to Solve the Segmentation Problem

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Abstract. *Considers the result of a comparative analysis of algorithms for filtering medical images obtained using computed tomography (CT). The objective of the study was to eliminate the noise that occurs in computed tomography images. The research was carried out on such types of filtration as Gaussian filtration and median filtration. During the study, random noise was applied to quantitative and qualitative evaluation of the application of each filter. The filtering methods considered were quantified using statistical parameters such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), and mean-square error (MSE). A qualitative assessment revealed that the median filter effectively eliminates the noise from the image. However, with an increase in the dimension of the image convolution kernel the requirements for computational resources correspondingly increase.*

Keywords: *medical imaging, image preprocessing, image filtering, image denoising, metrics.*

Introduction. Medical imaging plays a key role in the diagnosis and treatment of various diseases. Most of the imaging techniques used are associated with X-ray, CT, Magnetic resonance imaging (MRI), Positron emission tomography (PET), ultrasound, etc. Images obtained with X-rays, computed tomography (computed tomography) are the basis for radiation therapy. Most doctors prefer computed tomography, which is also used to assess the parameters of a diagnosed organ. Today, in order for artificial intelligence to be able to diagnose medical diseases using medical imaging data, their preliminary processing is necessary. In practice, it is often not always possible to identify useful information in the image. Some of this information is not recorded by the human eye due to poor contrast, background heterogeneity, high graininess, hardware defects and, therefore, cannot be analyzed. For example, the noise that any CT scan has is a major problem that limits image accuracy in any quantitative or qualitative measurement. This may be due to distortion caused by objects that actively reflect light, such as glass or iron. Therefore, preliminary filtering of the image is necessary. Elimination of noise during preliminary processing of CT images is one of the important steps for solving the segmentation problem, since the efficiency of subsequent stages of image processing directly depends on it. That is why an important factor for the successful segmentation of medical images in order to detect certain features and extract information from them is the application of various filters to the images.

Data preprocessing and cleaning are important tasks that must be completed before a dataset can be used to train a model. In the previous work of the authors [1], the data preprocessing process was carried out in the form of text normalization, implemented by methods of removing various characters, including numbers and punctuation marks, as well as excluding many auxiliary words imported as stop words from the natural language processing NLTK library [1]. If we consider the problem of pattern recognition, then it has its own specifics. Preprocessing techniques include various computer vision techniques such as filtering and segmentation. In existing works where such a comparative analysis was carried out the quality of the filtering algorithms used was not assessed, namely, the effectiveness of one or another algorithm was determined by a simple comparison of changes in the noise level, sharpness and other parameters. For example, in [2-4], the main algorithms for image filtering are considered, which were compared by simple signal-to-noise and performance ratios. However, the experiments carried out do not allow us to comprehensively investigate and get a complete picture of the quality of one or another filtering algorithm, since a simple ratio of one indicator to another is not a strict metric of image similarity. Another great example [5] analyzed filtering methods including proposing a new method and evaluated their quality by measuring distortion levels based on peak signal-to-noise ratio (PSNR) and mean square error (MSE). However, the subject of this study was ultrasound images, so a separate comparison is required for computed tomography images. Subsequently, the purpose of the work is to select a suitable filtering algorithm according to certain quality criteria of the image processed as a result and by visual evaluation. Therefore, the following tasks were formulated:

- to examine and apply the methods of linear and nonlinear filtering on the example of medical images, namely, computed tomography images;
- to conduct a comparative analysis of the effectiveness and relevance of various methods of filtering medical images by evaluating different metrics;
- to find out which algorithm is the most optimal for filtering a medical image based on the results of the comparative analysis.

Types of image defects. Image noise is defined by a change in brightness or chroma information and is usually a key characteristic when considering image quality. Accordingly, noise has different types. Additive Gaussian noise is characterized by adding values from the corresponding normal distribution with zero mean «to each pixel of the image. Moreover, it is usually introduced during the digital imaging stage. Impulse noise is characterized by the replacement of some of the pixels in the image with values of a fixed or random value. Such a noise model is associated, for example, with errors in image transmission» [2].

Filtering is the process of modifying or enhancing an image by strengthening or weakening any of its characteristics (noise, blur, sharpness, etc.). Filtering is divided into linear and non-linear. «Linear filtering is widely used in digital image processing. It is based on the use of fast convolution algorithms. Static filter masks do not always guarantee acceptable results. Linear filters lead to smoothing of brightness differences, and this in turn complicates the task of extracting boundaries. Nonlinear filtering has a number of advantages over linear filtering: it distorts brightness differences less, which makes it possible to more accurately find the boundaries of objects» [3] and removes impulse noise. There are a large number of algorithms for both the first and second types of image filtering. «The efficiency of these algorithms depends on both the algorithm itself and the image. For medical images obtained on different devices using different physical phenomena» [6], it is necessary to choose the right image processing algorithms. Comparison of filtering algorithms in order to choose the best one is an urgent problem [6].

Gaussian filter. Gaussian filter is a two-dimensional «convolution operator that is used to blur images and remove various noise. It uses a convolution kernel, which is the shape of a Gaussian («bell-shaped») hump. Let's describe in detail some of the special properties of this kernel. The Gaussian distribution for one-dimensional convolution has the form» [5]:

$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}, \tag{1}$$

where σ (1) is the standard deviation of the distribution. The distribution is graphically illustrated below.

«The idea behind a Gaussian Blur (Filter) is to use this bivariate distribution as a «point spread» function, respectively, this is achieved by convolution. Since the image is stored as a collection of pixels, we need to do a discrete approximation to the Gaussian function before we can convolution. In theory, the Gaussian distribution is non-zero, which would require an infinitely large convolution kernel, but in practice it is» [3] actually zero, so the kernel can be truncated at this point. It is not obvious how to choose mask values to approximate Gaussian. The gaussian value can be used at the center of the pixel in the mask, but this is imprecise because the gaussian value changes non-linearly across the pixel. We integrated the gaussian value over the entire pixel (by summing the gaussian in 0.001 steps). The integrals are not integers: we scaled the array so that the angles are 1. Finally, 273 is the sum of all the values in the mask [7].

Generally, we can conclude that the Gaussian filter has such an important advantage as effective noise suppression, but the resulting image after its application is deprived of fine details, while giving a more general picture. It can also be noticed that to significantly remove noise it is required to increase the size of the convolution kernel, thereby increasing the computational complexity.

Median filter. Median filtering is a non-linear technique used to remove noise from images. It is widely used because it is very effective at removing noise while preserving the edges of the image. Moreover, median filtering is especially effective at removing salt-pepper noise. The median filter works by moving through the image pixel by pixel replacing

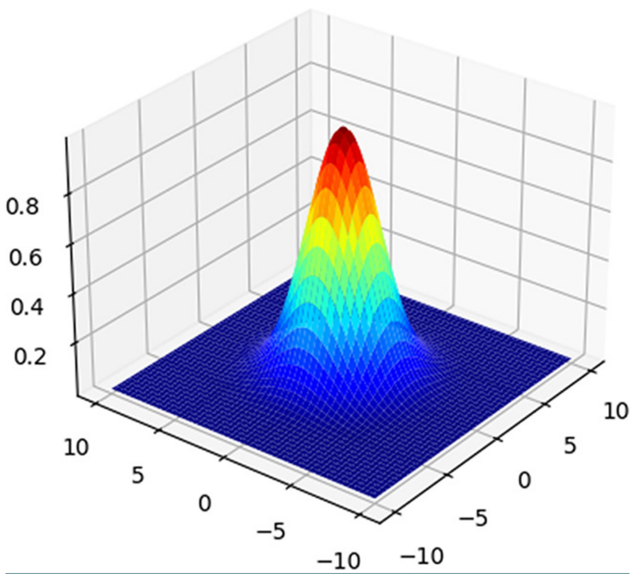

Figure 1 – Gaussian distribution for two-dimensional convolution, the mean deviation is (0,0), σ = 1

each value with the mean of neighboring pixels. The neighboring pixel pattern is a matrix called a «window» that moves pixel by pixel throughout the image 2 pixels across the entire image. The median is calculated by sorting all the pixel values from the window in ascending order and then replacing the pixel in question with the average (median) pixel value. As for the two-dimensional median filters they are presented at the following figure.

Median filtering is non-linear since the median of the sum of two arbitrary sequences $a(j)$ and $b(j)$ is not equal to the sum of their medians:

$$median[a(j)+b(j)] \neq median[a(j)] + median[b(j)]. \quad (2)$$

This inequality (3) can be verified by the example of sequences 30, 40, 50, 60, 70 and 120, 130, 140, 130, 120.

Various strategies for applying the median filter to suppress noise are possible. One recommends starting with a median filter that spans three image elements. If the signal attenuation is negligible, the filter window is expanded to five elements. This is done until median filtering is doing more harm than good. Another possibility is to perform cascaded median filtering of the signal using a fixed or variable window width. In general case, those areas that remain unchanged after a single treatment with a filter do not change after repeated processing. Areas in which the duration of the pulsed signals is less than half the width of the window will be subject to changes after each processing cycle [8].

Materials and methods of the research. Computed tomography images were selected as initial images for comparative analysis. The OpenCV computer vision and image processing library contains implementations of many algorithms of various types, including those that implement the filtering function. In this work, for comparative analysis, the cv2 and scikit-image libraries of the Python programming language were used as a tool, the simulation was carried out on an Intel Core i5 1.6 GHz, 8 GB RAM, with the Windows 10 operating system on a 64-bit processor.

Let's consider the application of the Gaussian and median filter on the example of medical images. The images were computed tomography images of the lungs provided by the dataset from The Cancer Imaging Archive.

Since the CT images are in DICOM format, we use pydicom library to extract information about them, including the images themselves. To carry out this experiment, random noise with a value of $\sigma = 0.03$

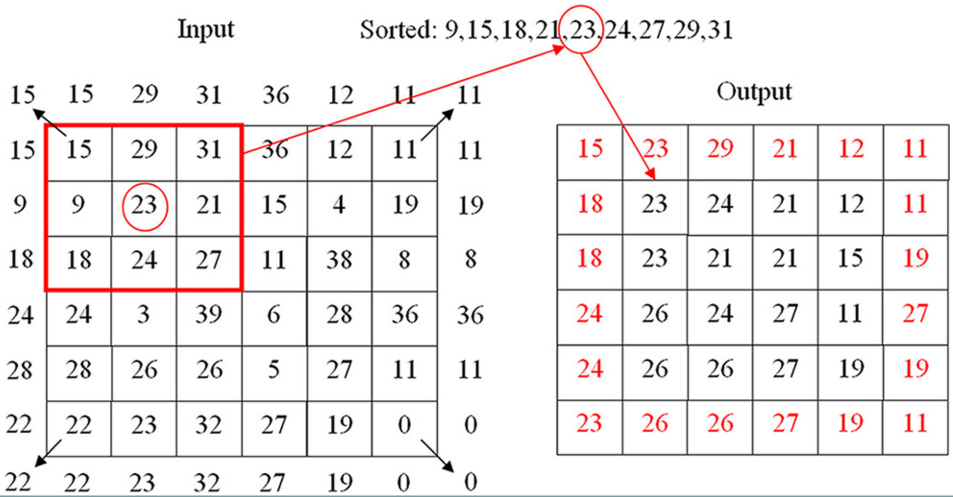

Figure 2 – Example of two-dimensional median filtering using a 3x3 window

Figure 3 – Initial medical Dicom image

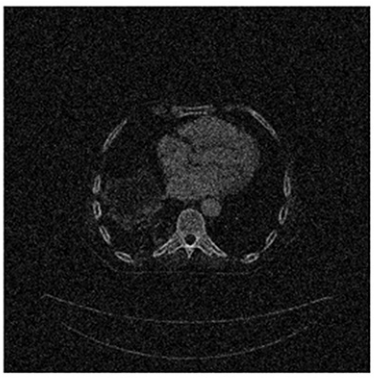

Figure 4 – The original image after applying noise

was applied to the original medical image.

Let us perform Gaussian filtering on the image with standard deviation (σ) values equal to 1, 1.5 and 2, respectively. The results are shown below.

The use of a Gaussian filter demonstrates that an increase in the parameter σ leads to a greater blurring of the image, but this is optimal only for a certain range of values of σ. The next figure below shows the results of applying median filtering using convolution windows of 3×3, 5×5, 15×15, respectively.

The median filter with 15×15 convolution window not only effectively removed noise, but also preserved the brightness and outlines within the image itself.

Analysis of the effectiveness of filtration methods. «There are two possible approaches to assessing the quality of images: objective or quantitative assessment using mathematical methods (mean-square error, measures that take into account the peculiarities of image perception by the human visual system) and subjective assessment based on expert assessments» [5]. In our case, a quantitative assessment was used, respectively, to analyze the effectiveness of filtering methods, the following types of measurements of the level of image distortion were applied [10]:

1) PSNR – peak signal-to-noise ratio;
2) SSIM – structural similarity index;
3) MSE – mean-square error.

The PSNR method is most commonly used to measure the level of distortion in image compression. It can be determined through the mean squared error (MSE). Typical PSNR values for lossy image and video compression are between 30 and 50 dB, assuming a bit depth of 8 bits, the higher the better. For 16-bit data, typical PSNR values are 60 to 80 dB [11].

SSIM is one way to measure the similarity between two images. The SSIM index is a full matching method, in other words, it measures quality based on the original image (not compressed or distorted). A distinctive feature of this method is that it takes into account the «error perception» by taking into account the structural change in information. The idea is that the pixels in an image have a strong relationship, especially when they are spatially close. These dependencies carry important information about the structure of objects in the image and the scene as a whole. The range of SSIM values is from –1 to +1, where SSIM equal to 1 means that the images are completely identical.

Another most common criterion for assessing image quality is the root mean square error (or MSE) estimate, calculated by averaging the squares of the differences between the intensities of the distorted and reference image pixels. This method is simple to calculate and has a clear physical meaning. The optimal value of this quality criterion is the lowest one obtained as a result of the calculation for several images [12].

After calculating all the parameters of the image quality, it was decided to also measure the noise level according to the method proposed by Immerkaer [13]. Immerkaer has proposed a simple and efficient way to calculate noise variance. Its essence consisted in suppressing the image structure using the Laplace operator and calculating the standard deviation of noise. This approach only required convolution and averaging operations without any statistical calculations, due to which it was fast. For the original image, the level of noise variance was calculated in advance and it was equal to 0.191.

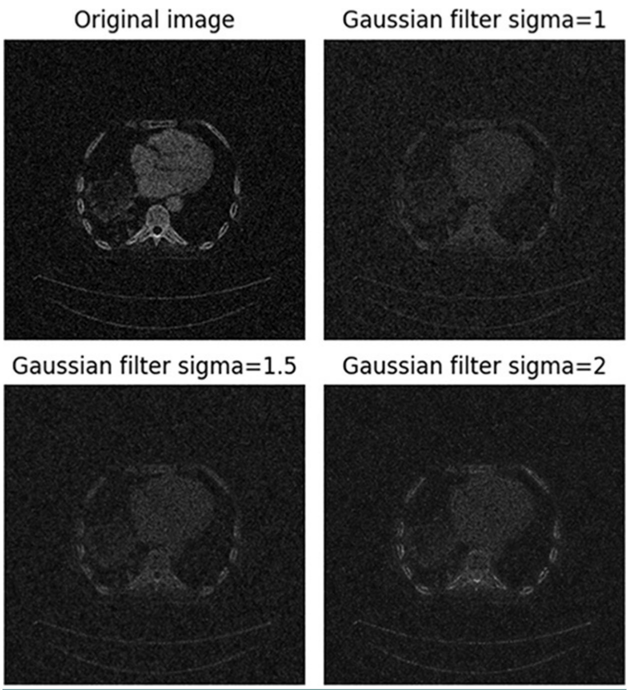

Figure 5 – Results of Gaussian filtration for σ = 1, 1.5, 2

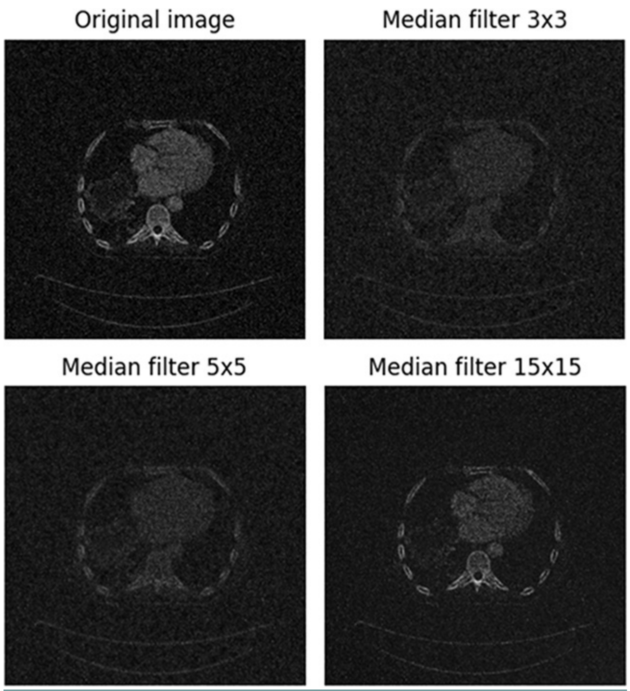

Figure 6 – Results of median filtering for convolution kernels measuring 3×3, 5×5, 15×15

Table 1 – Presents the results of applying image quality metrics for Gaussian filtering

Measure	σ = 1	σ = 1.5	σ = 2
PSNR	20.22	19.19	18.11
SSIM	0.46	0.30	0.23
MSE	0.010	0.012	0.015
σ	0.0047	0.00015	0.0002

Table 2 – Shows the results of applying image quality metrics for median filtering

Measure	Convolution window 3×3	Convolution window 5×5	Convolution window 15×15
PSNR	18.71	18.24	17.75
SSIM	0.28	0.17	0.10
MSE	0.015	0.016	0.017
σ	0.0327	0.0140	0.0022

Conclusions

This paper considered the effectiveness of three different medical image filtering methods tested using quantitative similarity scoring metrics. From the first point of view, with a visual qualitative assessment, it can be said with certainty that median filtering is the most efficient at eliminating noise. However, it should be noticed that the image to which the Gaussian filter has been applied has the lowest noise level according to the Immerkaer metric. Moreover, it should be noted that the estimated metrics of image similarity are not reference indicators, since it is necessary to take into account the individual characteristics of human perception of the image. Consequently, there is no strictly defined filter that would easily change such important image parameters as sharpness, noise level or color defects without any difficulties.

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Сегменттеу мәселесін шешу үшін медициналық КТ-кескіндерін сүзу әдістерінің салыстырмалы талдауы

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Аңдатпа. *Компьютерлік томография (КТ) негізінде алынған медициналық кескіндерді сүзу алгоритмдерінің салыстырмалы талдауының нәтижесі талқыланады. Зерттеудің мақсаты – компьютерлік томографиялық суреттерде пайда болатын шуды жоюдың оңтайлы сүзу алгоритмін табу. Зерттеу Гаусс сүзгісі мен медианалық сүзу сияқты түрлері бойынша жүргізілді. Зерттеу кезінде сүзгінің әр түрін қолдануды сандық және сапалық бағалау үшін кездейсоқ шу қолданылды. Қарастырылған сүзу әдістері сигналдың шуылға қатынасы (PSNR), құрылымдық ұқсастық индексі (SSIM) және түбірлік-орташа квадраттық қате (MSE) сияқты статистикалық параметрлерді қолдану арқылы сандық түрде анықталды. Сапалық бағалау медианалық сүзгі кескіннен шуды тиімді түрде кетіретінін көрсетті, алайда кескіннің конвульсиялық ядросы көлемінің ұлғаюымен сәйкесінше есептеу ресурстарына қойылатын талаптар да артады.*

Кілт сөздер: *медициналық бейнелеу, суретті алдын ала өңдеу, суретті сүзу, суреттің шуын азайту, көрсеткіштер.*

Сравнительный анализ методов фильтрации медицинских КТ-изображений для решения задачи сегментации

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Аннотация. *Рассматривается результат сравнительного анализа алгоритмов фильтрации медицинских изображений, полученных на основе компьютерной томографии (КТ). Задача исследования состояла в поиске оптимального алгоритма фильтрации для устранения шума, возникающего на снимках компьютерной томографии. Исследование проводилось на таких видах фильтрации, как гауссовская фильтрация и медианная фильтрация. В процессе исследования случайный шум был применен для количественной и качественной оценки применения каждого вида фильтра. Количественная оценка рассмотренных методов фильтрации осуществлялась с помощью таких статистических параметров, как пиковое отношение сигнала к шуму (PSNR), индекс структурного сходства (SSIM) и среднеквадратичная ошибка (MSE). Качественная оценка показала, что медианный фильтр эффективно удаляет шум с изображения, однако с увеличением размерности ядра свертки изображения соответственно возрастают требования к вычислительным ресурсам.*

Ключевые слова: *медицинская визуализация, предобработка изображения, фильтрация изображения, шумоподавление изображения, метрики.*

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