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COMPUTER TOMOGRAPHY IMAGES QUALITY ASSESSMENT

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Abstract*—The digital images quality estimating methods that are distorted by artifacts are considered. The most common types of artifacts are artifacts due to increased beam stiffness, the effect of partial volume filling, arbitrary patient movements during examination, etc. Quantitative and subjective measures are used to evaluate the quality of digital images. A comprehensive evaluation of the quality of tomographic images is proposed, based on the combination of the two above metrics, which will allow to better evaluate the quality of the tomographic image and to automate the evaluation process itself. A technique for evaluating the quality of tomographic images has been developed, which will allow for a more accurate diagnosis by eliminating the subjectivity of the physician.*

Index Terms—Artifacts; medical imaging; metrics; subjective measure, Gaussian filter; median.

I. INTRODUCTION

Computer tomography is one of the informative methods of noninvasive diagnostics that allow to study a wide range of objects (both biological and industrial) with different chemical composition and the ability to build three-dimensional models based on the data obtained.

Computer tomographs (CT) are the most commonly used in medical diagnostics and are characterized by relatively low operating costs and high throughput, and the main disadvantage of this method is the presence of X-rays.

Informativeness is influenced by a number of factors, which depend, first of all, on the physical and technical principles of the method implementation. Restrictions on the use of computed tomography are related both to the design of the scanner itself and to the sensitivity to external conditions, such as fluctuations in ambient temperature. In X-ray analysis, mistakes are often made in making decisions, as they are related to the psychophysiological condition of the researcher, features of the visual analyzer, shooting conditions and image viewing, media quality [2], [7], 18].

Overall, CT quality is characterized by five factors: spatial resolution, contrast, noise or spatial homogeneity, linearity, and the presence of artifacts. The appearance of artifacts can not only reduce the visual quality of the images, but in some cases make them completely unsuitable for medical diagnosis.

Moreover, assessment of radiological examination data to date is accompanied by a significant proportion of subjectivism, and therefore the development new CT scan assessment methods, which allow to objectively determine the form and severity of the disease.

II. PROBLEM STATEMENT

There is a problem with the lack of a single assessment of the quality of the tomography images, the lack of automation of the process and the presence of subjectivity in the role of medical staff. It's necessary complete the following tasks to try to resolve these issues.

1) Analyze available digital image quality assessment techniques.

2) Consider global trends in improving tomographic imaging and reducing physician subjectivism in diagnosis.

3) To develop a technique for evaluating the quality of tomographic images.

4) To test the results of the evaluation of the quality of the test tomographic images.

Tomography is a radiological examination technique that allows you to obtain a slice image at a certain depth of the object under study (Fig. 1).

A conventional tomographic image is obtained by moving the emitter and the X-ray film in opposite directions in such a way that the shadows of the organs outside the layer are blurred while moving and the image of the layer remains clear (Fig. 2).

All medical image diversity, regardless of how they are obtained, can be attributed to one of two main groups: analog and digital (matrix) images.

Analog images include those that carry continuous information. For example, images on ordinary radiographs, scintigrams, thermograms.

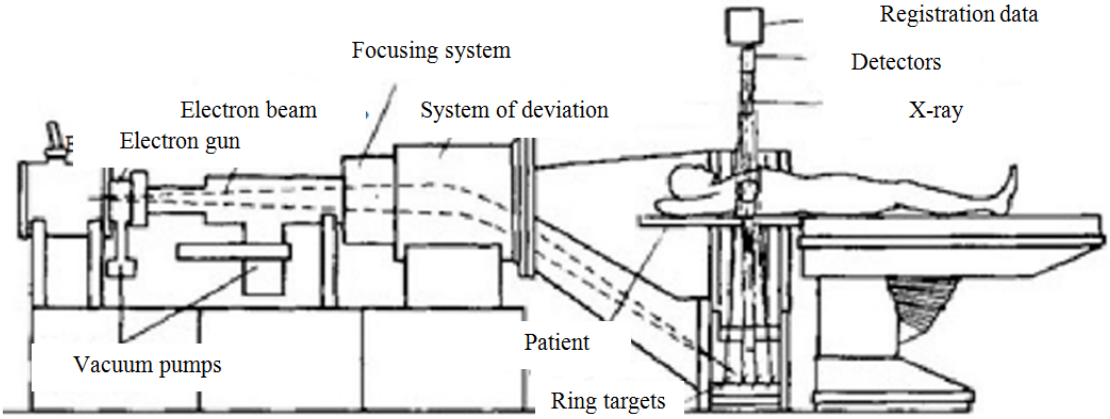


Fig. 1. Computer tomographs system

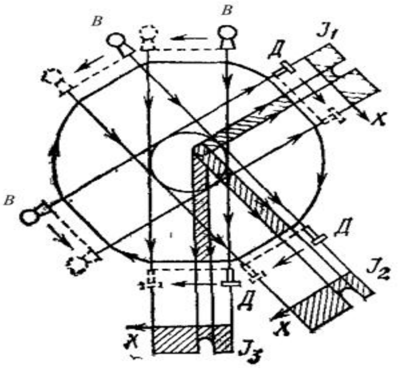


Fig. 2. Signal recording scheme

Digital (matrix) images are those obtained with a computer. They basically have a matrix (raster) stored in the memory of the PC.

A raster consists of a large number of cells - pixels, or, by volume, voxels. Accordingly, the more pixels a raster has, the better the image quality. When processing such images, their deformation is possible, which is related, in particular, to the resizing of the images. This gives the grain and the detail of the image is lost. In radiology, this phenomenon is observed when trying to make paper copies in digital fluorography and computed tomography.

The matrix image is formed by scanning electronically by rows. This creates an opportunity for real-time image perception. For this purpose a special display processor is used, which is connected to the main computer through a communication system (interface) (Fig. 3).

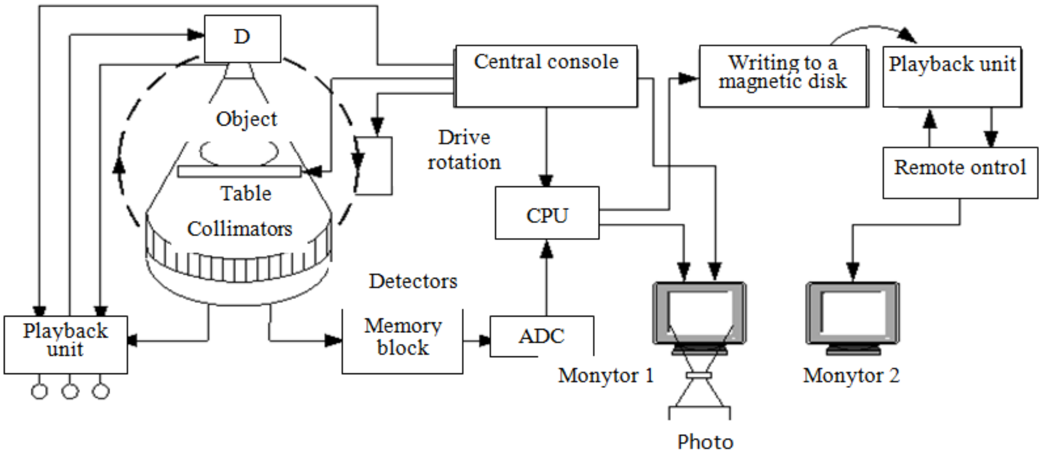


Fig. 3. Flowchart of computed tomography complex

Contribution of structures not related to this pixel is only possible if the object does not change during the measurement.

Thus, the discrepancy of the measured data is always reflected in the image in the form of distortions.

However, such distortions are not always noticeable immediately, as they sometimes appear only in the form of erroneous CT numbers, which often occurs, for example, by increasing the stiffness of the radiation beam due to unequal radiation weakening in different regions of the polychromatic X-ray spectrum, depending on the energy of the radiation type, and direction of projection.

As a result, after passing the beam through the thick structures, especially the bone, the energy of its spectrum increases, which results in the dependence of the measured values of the attenuation coefficient, which is a function of the average radiation energy, on the direction of the projection and, accordingly, to obtain inappropriate data. This is usually shown in the image as high density zones. In the case of soft tissues similar in effect to the rigidity of the bundle with water, these effects can be corrected, but it is difficult to perform simultaneous correction for water, bone, and a specific substance.

Some manufacturers of tomography systems propose to introduce a special correction for bone tissue in brain tomography. The operator's ability to correct such artifacts is generally quite limited.

Artifacts due to the effects of partial volume filling occur when only part of the high contrast structure is in a measured slice, which in the longitudinal direction (Z-axis) of the detector elements measure the average radiation intensity and not the attenuation, while inevitably ignoring the logarithmic dependence.

Therefore, such artifacts are often referred to as "nonlinear distortions due to partial filling effects". Partial fill-in artifacts can only be managed with thinner sections. In order to avoid excessive noise levels, several sections are summed up, resulting in a thicker image, but with less noise and artifacts. The effects of partial volume filling may occur not only in the z-axis but also in the slice plane. These artifacts are commonly referred to as sampling artifacts, and they appear mainly on the borders of areas of very high contrast, such as near metal objects [2], [9].

III. QUALITY SCORES FOR DIGITAL IMAGE ANALYSIS

The image is intended to represent information in a visual form. It is one of the most convenient forms of presentation of information in the diagnosis of human organs in medicine. The effectiveness of a person's perception of this information depends on many factors. Consideration of the influence of these factors is possible provided the study of a number of issues related to the methods of obtaining, the properties of visual perception and image processing.

The task is to develop a technique for evaluating the image quality of computer tomography, which will adequately evaluate the quality of the image when exposed to the above artifacts [2], [14] – [16], [18].

Subjective measure is the expert evaluation of image quality (in this case, the experts are radiologists). A quantitative measure is the use of computer science and mathematical methods that are more accurate and objective. In turn, quantitative measures of quality are divided into absolute and comparative ones. Comparative measures of digital image quality include, for example, the Minkowski norm and so-called metrics:

- peak signal-to-noise ratio (PSNR);
- a measure of the structural similarity of the images (SSIM).

Each of these metrics has its advantages and disadvantages, so it is appropriate to combine them.

There are two possible approaches to image quality assessment: quantitative evaluation using mathematical methods and subjective evaluation based on expert evaluation [18].

The subjective assessment of image quality depends on various external factors, such as environmental conditions, lighting, mood of the evaluator, monitor quality, characteristics of the images received, etc. There are two types of peer reviews: absolute and comparative. The human visual system is the most reliable and sophisticated measuring tool that evaluates the quality of a digital image. However, subjective assessment is a rather difficult and slow process that requires experienced experts and is not objective and universal..

Quantitative measures of image quality, as well as subjective, can be divided into two groups: absolute and comparative. An absolute measure is a number comparable to any image based on the analysis of that image. A comparative measure is the numerical result of comparing two or more images. It's possible to use absolute measures calculated for each image individually for comparison.

Image sharpness is one of the most important indicators of its quality, largely determining the suitability of the image for further processing. The sharpness of the image is the degree of blurring of the boundaries between two adjacent portions of the image with different optical density (brightness) [18].

It's proposed by formulas (1), (2) to determine the degree of sharpness of the image by finding the angle of inclination of the image brightness profile at the edge of the difference:

$$V_i = \mathrm{tg}\alpha = \frac{G}{w}, \tag{1}$$

$$S_i = \mathrm{tg}\alpha = \frac{I(a) - I(b)}{w}, \tag{2}$$

where i is the number of edge pixels in an image; w is the width of the difference; G is the difference between the brightness values of the pixels, which are denoted as a and b.

Another parameter that determines image quality is contrast. Contrast is a gradation characteristic of a black and white or color image by the difference in (color saturation of its brightest and darkest areas [3], [10].

Since the image has a complex plot character, it creates the need to determine the contrast of the contrast of individual combinations of image elements. In this case, all elements are considered equal and the contrast of each pair is calculated by the formula:

$$C_{ij} = \frac{L_i - L_j}{L_i + L_j}, \tag{3}$$

where L_i, L_j are brightness of the image elements.

The pixels to compare can be choosed by different ways. The simplest way is to compare adjacent pixels in horizontal and vertical directions by the formula (3).

Next, using the rule of contrast contrast, calculate a set of values that determine the perception of each pair of image elements. By averaging the matrix of local contrasts, the total contrast is obtained. The result can be used as one of the parameters for assessing the visual quality of the image.

Equally important are comparative measures for assessing the quality of digital images, such as the Minkowski norm, which estimates the difference between two images $X = \{x_{ij}\}$ and $Y = \{y_{ij}\}$ by the formula:

$$L_p = \left[\frac{1}{MN} \sum_{i-1}^{M} \sum_{j=1}^{N} \left| x_{ij} - y_{ij} \right|^p \right]^{1/p}, \tag{4}$$

where L_p is the value of the Minkowski norm; $X = \{x_{ij}\}$ and $Y = \{y_{ij}\}$ are comparable images; M, N are image sizes, $p = 1, 2, 3, ...$

The value when comparing identical images is zero. Minkowski's norm does not take into account the structural similarity of images. The structural information of the original image is almost completely lost in the second test example, but stored in the first. To calculate the Minkowski norm, we first subtract the output signal from the test signals, obtaining erroneous signals 1 and 2, which have a completely different structure. However, applying the absolute operator to the obtained results gives the same absolute error. And, as a consequence, the same values of Minkowski norms, even with different parameter values p.

Minkowski's norm does not always correspond to the visual assessment of the similarity of images that have the same meaning of the norm. It also shows that image structural information plays an important role in image quality assessment methods [11].

Peak signal to noise ratio (PSNR) shows the ratio between the maximum of the possible signal value and the noise-distorting power of the signal. Since many signals have a wide range, PSNR it is customary to measure on a logarithmic scale in decibels. The greater the value PSNR, the more similar are the comparable images.

The formula for determining PSNR is as follows:

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{\mathrm{MAX}_I^2}{\mathrm{MSE}}\right) = 20\log_{10}\left(\frac{\mathrm{MAX}_I}{\sqrt{\mathrm{MSE}}}\right), \tag{5}$$

where MAX_I is the maximum image pixel value; MSE is the standard error of the image.

Scientific studies that correlated the PSNR metric with the peer review state that a PSNR of sufficient human quality should be greater than 25 dB and satisfactory jpeg image quality is considered to be 35 db [4], [5], [12].

Structural Similarity Index (SSIM) – Compares two input images. But unlike the first metric, this method takes into account "error perception", because it takes into account the structural change of information:

$$\mathrm{SSIM}(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}, \tag{6}$$

where μ_x is the average x; μ_y is the average y; σ_x^2 is the dispersion x; σ_y^2 is the dispersion y; σ_{xy} is the covariance x, y; $c_1 = (k_1 L)^2, c_2 = (k_2 L)^2; L$ is the dynamic pixel range; k_1 is the constant with value 0,01; k_2 is the constant with value 0.03.

Pixels have a strong relationship when they are in space. This metric is measured as a percentage [6], [13].

IV. COMPREHENSIVE ASSESSMENT OF THE QUALITY OF TOMOGRAPHIC IMAGES

Within the limits of the conducted research the technique of complex estimation of the quality of tomographic images was developed, which compares the metric of structural similarity with the metric which shows the relation between the maximum of the possible signal value and the noise power. None of the above gives an unambiguous answer to the question of how best to evaluate the quality of the image relative to the original. Following the research, a new technique was proposed in this paper, which includes the following metrics:

- **PSNR;**
- **SSIM.**

For complex image estimation, it is proposed in this work to introduce a variable p_{comp} that will include both of the above normalized metrics and to calculate complex estimation by the formula:

$$p_{\text{comp}} = \frac{p_1 k_1 + p_2 k_2}{2}, \tag{7}$$

where p_1 is the normalized score PSNR in the range from 0 to 1; p_2 is the normalized SSIM score from 0 to 1; $k_1 k_2$ are weights from 0 to 2, but $k_1 + k_2 \leq 2$.

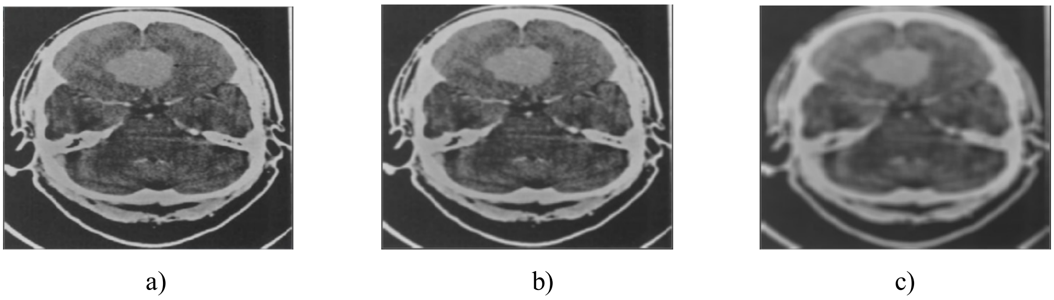
Thus, a comprehensive evaluation considers two metrics. Weighting factors can be changed if necessary for a particular metric to have a greater impact on the final estimate in a specific task or on a specific dataset. This paper uses a weighting factor of 1 for both the first and second metrics. Enough image quality values for metrics SSIM and p_{comp} are at least 80% and 0.8 respectively [14].

V. COMPARISON OF METHODS AND ANALYSIS OF RESULTS

To analyze the quality of the integrated quality assessment, it was used alternately to evaluate images filtered by a Gaussian filter with 3×3, 5×5, and 13×13 masks and a median filter with 3×3, 5×5, and 13×13 windows. These filters were used as artifacts in computed tomography. Modeling of the developed methodology was performed on own software, which was created in C ++ programming language using OpenCV library. Figures 4, 5a, b, c, and 6a, b, c help to clearly understand evaluate these filters in the role of artifacts and analyze their impact on the quality of the tomographic image.

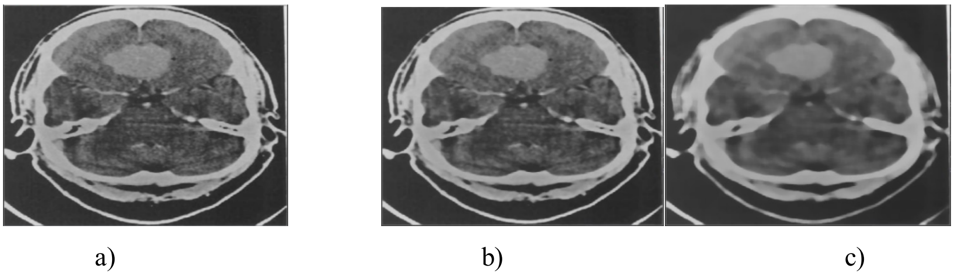
Fig. 4. Reference image

Table I shows the results of the developed software.



a) b) c)

Fig. 5. The image is filtered by a Gaussian mask mask 3×3 (a), 5×5 (b), 13×13 (c) in accordance



a) b) c)

Fig. 6. The image is filtered with a 3×3 (a), 5×5 (b), 13×13 (c) median filter, respectively

TABLE I. RESULTS OF METRICS WHEN EVALUATING IMAGE QUALITY PROCESSED BY A GAUSSIAN AND ARTIFACT MEDIAN FILTER

Filter	The size of the filter kernel	PSNR, dB	SSIM, %	p_{comp}
Gauss	3×3	35.301	96	0.92
	5×5	29.38	89	0.81
	13×13	21.48	62	0.57
Median	3×3	39.59	97	0.98
	5×5	34.1	92	0.88
	13×13	23.13	72	0.65

Based on the table data we can conclude that filters with masks (windows) 13×13 significantly impair the quality of the tomographic image and make it uninformative for diagnosis.

VI. CONCLUSIONS

Within the framework of the work, the types of images and imaging methods in medicine were analyzed, as well as the metrics of image quality assessment. He showed that despite the fact that there are fast and high quality algorithms, new techniques are emerging that will give objectively better results. A comprehensive evaluation of the quality of the processed images relative to the original was proposed. Software for quality assessment of tomographic images has also been developed.

Further research focuses on finding software optimizations to implement the proposed methodology. It is advisable to consider applying other filters, more metrics, and other ways to combine them.

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В. В. Кернешел, О. Б. Іванець, О. В. Мельников. Оцінювання якості зображень комп'ютерної томографії

Розглянуто методики оцінювання якості цифрових зображень, які спотворені артефактами. Найбільш поширеними видами артефактів є артефакти через підвищення жорсткості пучка випромінювання, ефект часткового заповнення об'єму, довільні рухи пацієнта при обстеженні та ін. Для оцінювання якості цифрових зображень застосовують кількісні і суб'єктивні міри. Запропонована комплексна оцінка якості томографічних зображень, яка базується на поєднанні двох вищевказаних метрик, що дозволить краще оцінити якість томографічного зображення і автоматизувати сам процес оцінки. Розроблено методику оцінювання якості томографічних зображень, що дозволить більш точно ставити діагноз виключивши суб'єктивізм лікаря.

Ключові слова: артефакти; медичні зображення; метрика; суб'єктивна міра; фільтр Гауса; медіанний.

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В. В. Кернешел, О. Б. Иванец, О. В. Мельников. Оценка качества изображений компьютерной томографии

Рассмотрены методики оценки качества цифровых изображений, искаженные артефактами. Наиболее распространенными видами артефактов есть артефакты из-за повышения жесткости пучка излучения, эффект частичного заполнения объема, произвольные движения пациента при обследовании и др. Для оценки качества цифровых изображений применяют количественные и субъективные меры. Предложенная комплексная оценка качества томографических изображений, основанная на сочетании двух вышеуказанных метрик, что позволит лучше оценить качество томографического изображения и автоматизировать сам процесс оценки. Разработана методика оценки качества томографических изображений, что позволит более точно ставить диагноз, исключив субъективизм врача.

Ключові слова: артефакты; медицинские изображения; метрика; субъективная мера; фильтр Гауса; медианный.

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