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МЕТОДЫ И ПРИЛОЖЕНИЯ ЦИФРОВОЙ ОБРАБОТКИ СИГНАЛОВ
METHODS AND APPLICATIONS OF DIGITAL SIGNAL PROCESSING

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TESTING SOFTWARE FOR INCREASING THE VISUAL PROPERTIES OF DIGITAL IMAGES

САНДЫҚ БЕЙНЕЛЕРДІҢ ВИЗУАЛДЫ ҚАСИЕТТЕРІН ЖАҚСАРТУҒА АРНАЛҒАН БАҒДАРЛАМАЛЫҚ ҚАМТАМАНЫ ТЕСТІЛЕУ

ТЕСТИРОВАНИЕ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ ДЛЯ ПОВЫШЕНИЯ ВИЗУАЛЬНЫХ СВОЙСТВ ЦИФРОВЫХ ИЗОБРАЖЕНИЙ

***Abstract**. This article discusses the algorithm and the results of the software implementation, which was developed during the creation and research of algorithms to improve the visual properties of digital images. Images from the TID2013 database were used as a test image to test the results of the software. A database of digital images MyImages with different types of distortion from real scenes was created. Evaluation measures were used to validate the quality evaluations of digital images. Pearson's correlation is used for comparison with a reference, and the CLRIQA algorithm is used to evaluate images without a reference. Visual evaluation of the quality of digital images was carried out using social networks. All processed images were estimated on a 5-point scale: 1 – satisfied, 2 – bad, 3 – satisfied, 4 – good, 5 – very good. All results were validated by indicators. Pearson's correlation coefficient, Spearman's rank correlation and Kendell's correlation coefficient were used to determine the compliance between objective and subjective evaluations. The final testing of the proposed algorithms based on MyImage and TID2013 shows the best result in the range of [0.71-0.83]. This testifies that the objective indicators of image evaluation agrees well with the visual opinions. The developed algorithms for improving the visual quality of digital images are integrated into the AutoImage program. This program received a certificate of state registration of a computer program (rights No. 30080 dated November 8, 2022).*

***Keywords:** image quality, digital image, image evaluation, unreferenced evaluation, objective indicators.*

***Аңдатпа**. Бұл мақалада сандық бейнелердің визуалды сапасын жақсартуға негізделген алгоритмдерді құру және зерттеу барысында әзірленген бағдарламалық қамтаманың алгоритмі мен оны жүзеге асырудағы нәтижелері қарастырылады. Бағдарламалық қамтаманың нәтижелерін тестілеу үшін сынақ бейнелері ретінде TID2013 бейнеқорындағы цифрлық бейнелер пайдаланылды. Сондай-ақ, әртүрлі бұрмалану түрлері бар нақты көріністерден құрылған MyImages цифрлық бейнелер қоры қолданылды. Цифрлық бейнелердің сапасын растау үшін бағалау өлшемдері қолданылады. Суреттерді эталонмен салыстыру арқылы бағалау үшін Пирсон корреляциясы, суреттерді эталонсыз бағалау үшін CLRIQA алгоритмі қолданылады. Сандық бейнелердің сапасын визуалды бағалау әлеуметтік желілері арқылы жүзеге асырылды. Барлық өңделген суреттер 5 балдық шкала бойынша бағаланды: 1 – қанағаттанарлықсыз, 2 – нашар, 3 – қанағаттанарлық, 4 – жақсы, 5 – өте жақсы. Барлық нәтижелер көрсеткіштермен расталады. Объективті және субъективті бағалаулар арасындағы сәйкестік дәрежесін анықтау үшін Пирсон корреляция коэффициенті, Спирмен дәрежелі корреляция және Кенделл корреляция коэффициенті қолданылады. MyImage және TID2013 бейнелер қорын қолданып жүргізілген* *тестілеудің қорытындысында корреляция коэффициенті 0,71-дан 0,83-ке дейін ауытқиды. Бұл көрсеткіштер бейнені бағалаудың объективті өлшемдерінің визуалды пікірлермен жақсы сәйкес келетінін көрсетеді. Сандық бейнелердің визуалды сапасын жақсарту үшін әзірленген алгоритмдер AutoImage бағдарламасына біріктірілген және ЭЕМ бағдарламасына авторлық құқықты растайтын мемлекеттік тіркеу туралы куәлік алынған (2022 жылғы 8 қарашадағы № 30080 құқық).*

***Түйін сөздер**: бейне сапасы, сандық бейне, бейнені бағалау, эталонсыз бағалау, объективті көрсеткіштер*

***Аннотация**. В данной статье рассматриваются алгоритм и результаты реализации программного обеспечения, которые были разработаны в ходе создания и исследования алгоритмов для повышения визуальных свойств цифровых изображений. Для тестирования результатов программного обеспечения в качестве тестового изображения использованы изображения из базы TID2013. А также создана база цифровых изображений MyImages с разными типами искажения из реальных сцен. Чтобы подтвердить оценки качества цифровых изображений используются меры оценки. Для сравнения с эталоном используется корреляция Пирсона, для оценки изображений без эталона используется алгоритм CLRIQA. Визуальная оценка качества цифровых изображений проводилась с помощью социальных сетей. Все обработанные изображения оценивались по 5 бальной шкале: 1 – неудовлетворено, 2 – плохо, 3 – удовлетворено, 4 – хорошо, 5 – очень хорошо. Все результаты подтверждены показателями. Для определения степени соответствия между объективными и субъективными оценками используются коэффициент корреляции Пирсона, ранговая корреляция Спирмена и коэффициент корреляции Кенделла. Итоговое тестирование предложенных алгоритмов на базе MyImage и TID2013 показывает лучший результат в диапазоне [0,71-0,83]. Это свидетельствует о том, что объективные показатели оценки изображений хорошо согласуются визуальными мнениями. Разработанные алгоритмы для улучшения визуального качества цифровых изображений интегрированы в программу AutoImage, на которую получено свидетельство о государственной регистрации программы для ЭВМ (права №30080 от 8.11.2022 года).*

***Ключевые слова**: качество изображения, цифровое изображение, оценка изображений, безэталонная оценка, объективные показатели.*

Introduction. Digital processing and digital analysis of images are increasingly being used in various fields of science and technology, such as intelligent robotic systems, industrial control systems, control systems for moving vehicles, remote sensing data processing, biomedical research, new document processing technologies, and many others. The problem of improving image quality holds a prominent place in all areas related to the processing and reproduction of digital images [1-3].

Image acquisition, storage, transmission, viewing, and processing technologies have undergone incredible advances in recent years. Nowadays, the number of digital devices that reproduce digital images is increasing. The resulting digital images are often subject to various distortions, which leads to significant quality fluctuations. Examples of distortions occur during image capture, compression, transmission, post-processing, etc. For example, incorrect focus, a poor quality lens, or a shaky hand operating the camera can blur the image. Long exposures or high sensitivity of ISO can increase image noise pollution. Image data is often subjected to compression algorithms that degrades image quality. Poor quality images can reduce the accuracy of various algorithms of personality recognition, medical and satellite images processing. Accordingly, there is a need to improve the quality of these images. Therefore, in line with current trends in improving the quality of digital images, it is necessary to develop algorithms and improve existing methods for digital image processing, which allow improving the visual quality of digital images in automated mode.

Quality scores are needed to determine if one image is of better quality than another. Evaluation of image quality based only on appearance can be biased, therefore, quantitative indicators are crucial for qualitative comparison of images.

There are two main classes of image quality evaluation methods [2-5]: subjective and objective. In a subjective evaluation, looking at two images, a person can conclude that one is better than the other or they are about the same. He can rank 3-5 images by visually assessing their quality, for example, on a five-point scale: very low, low, average, above average, high.

A popular criterion for subjective evaluations of the quality of digital images at the moment is a metric that can be written as [2]]:

$$d_{i,j} = r_{i,ref}(j) - r_{i,j},$$

$$DMOS_{i,j} = \frac{d_{i,j} - \overline{d_i}}{\sigma_i},$$

$$DMOS_j = \overline{DMOS_{i,j}}$$

Where r_{ij} is the evaluation of the *i*-th expert for the j image, $r_{i,ref}(j)$ denotes the quality evaluation that the *i*-th expert gave to the reference image,

D_i is the average value of evaluation over all images, which is set by the i-th expert, and σ_i is the standard deviation. The DMOS metric takes values from 0-100. The larger the value, the worse the quality of the tested image.

It is difficult to visually evaluate the quality of tens or hundreds of images, and it is almost impossible to rank them by quality level. This problem has given rise to a variety of measures and functions that compute objective evaluations of digital images. Objective evaluation of images is performed algorithmically. Such an algorithm can use the original image to evaluate the quality, that is, be referenced, or it can determine the quality without the presence of an undistorted copy of the image, that is, be unreferenced.

The main criteria for an objective evaluation of image quality are that the automatic evaluation must correspond to the subjective MOS or DMOS metrics for the same images. To establish the degree of correspondence between objective and subjective evaluations, various metrics are used: Pearson's correlation coefficient, Spearman's rank correlation and Kendell's correlation coefficient [5].

Digital image quality evaluation has many applications in practice and plays a central role in the development of many image processing algorithms and systems, as well as in their implementation, optimization and testing.

Literature review. Image enhancement is the improvement of image quality to a better and more understandable level of visual appearance for future automated image processing such as analysis, detection, segmentation, and recognition. Over the years, due to the development of the field of image processing, many image enhancement methods have been proposed. Existing digital image processing technologies make it possible to solve a fairly complex range of practical problems of identification, segmentation, measurement, recognition, etc. The main problem of known image enhancement software products [6-9] is to define enhancement criteria. Several image enhancement methods are empirical and require interactive procedures to obtain satisfactory results. The authors [6] aim to develop methods that can first track user preferences in the training set and then learn a model of these preferences to personalize image enhancement. In [7], the user's preferences are estimated using RankNet, then the image enhancement parameters are optimized to maximize the implied preference. Similarly, Hu et al. [8] use generative adversarial networks to learn latent space from a pre-expanded collection of photographs and then sample from this space to edit invisible images. Article [9] presents image enhancement personalization methods that can be deployed in photo editing software as well as cloud image sharing services. The proposed system [9] is based on a new interactive application that collects the user's improvement preferences. The authors propose algorithms for predicting personalized improvements by learning a preference model based on the information provided. Semi-automated image enhancement software helps users enhance the visual appeal of images, however, requires depth knowledge of manual image editing.

Therefore, automatic image processing is relevant for image analysis systems of various nature and computer vision in general.

Materials and methods of research. This article discusses the algorithm and the results of the software implementation, which were developed during the creation and research of algorithms to improve the visual properties of digital images.

The software is designed to improve the visual quality of raster and color digital images. The software algorithm is based on digital noise reduction, deblurring, contrast management, and digital image restoration after JPEG2000 compression. The block diagram of the algorithm is shown in Figure 1.

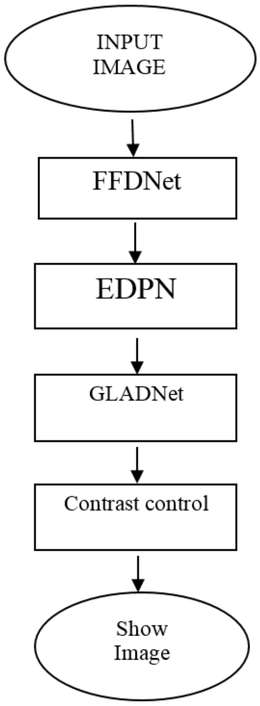

Figure 1. Block diagram of the algorithm

FFDNet[10][11] is the latest image denoising method based on the Convolutional Neural Network architecture. Unlike other existing neural network denoising tools, FFDNet has several desirable properties, such as faster execution time and less memory, and the ability to handle a wide range of noise levels with a single network model. The combination of noise reduction performance and lower computational load makes this algorithm attractive for practical noise reduction applications.

EDPN[12][13] is designed to restore a blurry image by making full use of intrinsic and inter-scale similarity in a degraded image.

GLADNet[14][15] solves the problem of low light enhancement. The basic idea of the algorithm is calculate the overall lighting score, then adjust the light and complete the details using concatenation with the original input. The input image is scaled to a certain size and then placed in an encoder-decoder network to obtain a global lighting a priori. For detailed reconstruction of the input image, a convolutional neural network is used.

Power transformations are used to control contrasts, reduce or increase the brightness of images, which have the form:

$S = c \cdot r^{\gamma}$, where c and γ are positive constants.

When γ>1, the image brightness decreases, power transformations in this case are used to eliminate too light areas of the image, and for γ <1, the image brightness increases. Note that the amplitude response of many devices used to capture, print, or render images follows a power law. The procedure used to correct such a power characteristic is called gamma correction.

The AutoImage software consists of four tabs: Load Image, Enhance Image, Edit Contrast, Save Image. The Python 3.7 development environment for the Microsoft Windows 10 operating system was used to create the software. The main part of the program is written in Python, some algorithms for digital image processing are implemented in MatLab2018 and C ++. The general view of the software interface is shown in Figure 2.

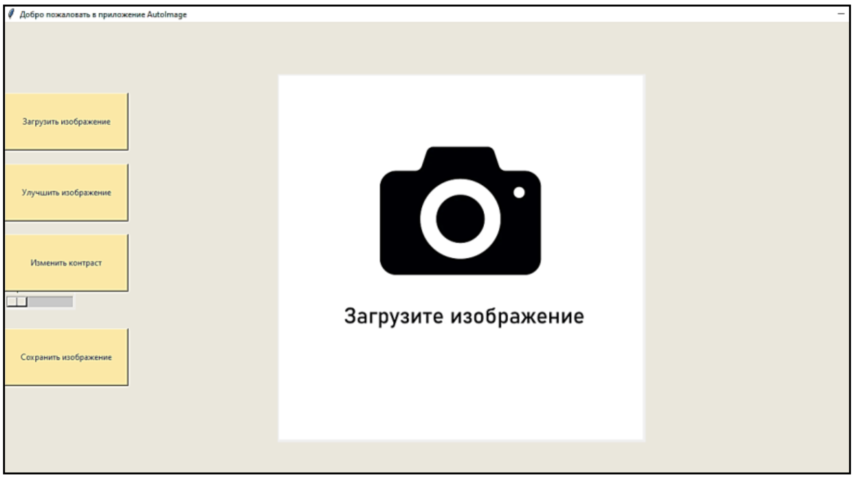

Figure 2. AutoImage software interface

To test the results of the software, images from the TID2013 database[2] were used as a test image. A database of digital images MyImages with different types of distortion from real scenes was also created. The MyImages image database contains 18 digital images with distortions as noise, blur, low contrast and compressed images. Images from the MyImages database are shown in Figure 3.

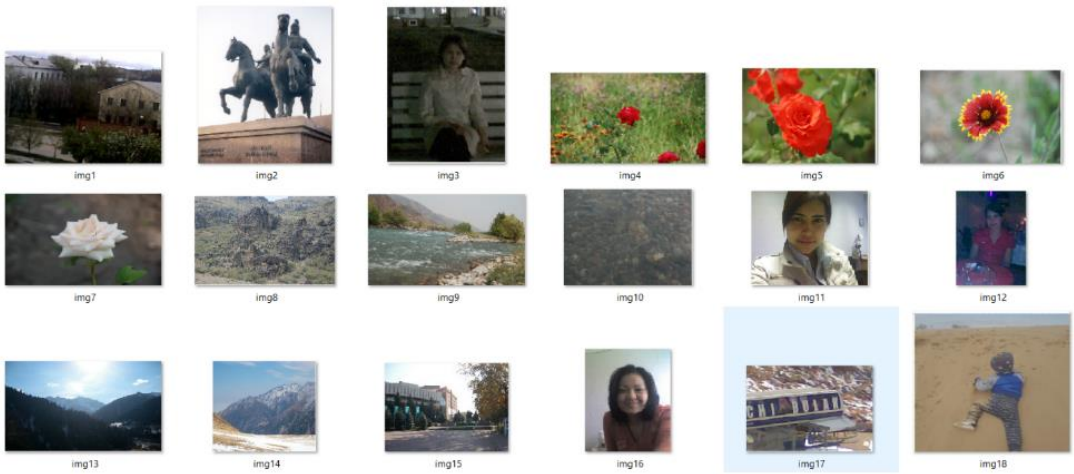

Figure 3. Images from the MyImages database

Quality metrics are needed to decide that one image is of better quality than another. Otherwise, comparing image quality based only on appearance may be biased, therefore, quantitative indicators are crucial for comparing images in terms of their quality. Pearson's correlation[17] is used for comparison with reference and validation image enhancement and visual image quality. Pearson's correlation was not carried out for images from the MyImages database because it has no reference. To evaluate images without a reference, the CLRIQA[18][19] algorithm is used. All results are confirmed by indicators and recorded in Table 1.

All test images are processed with this software. Sample images are shown in Figures 4 and 5.

Figure 4. Sample images from the MyImages database

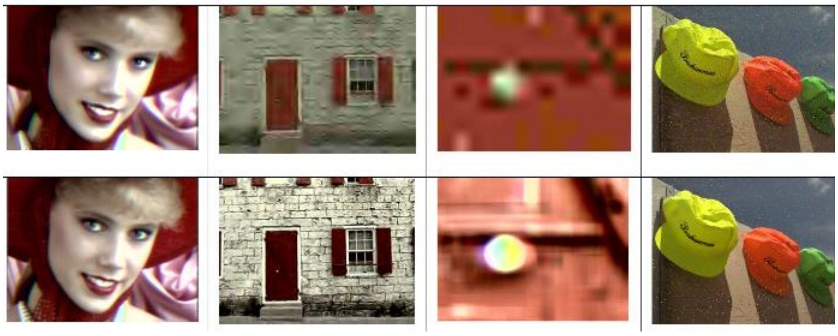

Figure 5. Sample images from the TID2013 database

All enhanced images were visually evaluated using social networks. All processed images were evaluated on a 5 – point scale: 1 – unsatisfied, 2 – bad, 3 – satisfied, 4 – good, 5 – very good.

Table 1. Objective and visual evaluations of enhanced images (mean)

Image databases	Number of images	Objective evaluations		Visual evaluations	average runtime
		Pearson correlation	CLRIQA		
TID2013	600	0.873	0.886	4.46	116.312 sec
MyImages	18		0.835	4.35	118.105 sec

Pearson's correlation coefficient, Spearman's rank correlation and Kendell's correlation coefficient were used to determine the degree of agreement between objective and subjective evaluations.

Table 2. Correlation coefficient between objective (CLRIQA) and subjective evaluations

Image databases	Pearson correlation	Spearman correlation	Kendell correlation
TID2013	0.79	0.83	0.72
MyImages	0.77	0.81	0.71

Conclusion. The correlation coefficient can take values from −1 to +1. If the value is closer to 1, then this means the presence of a strong connection, and if it is closer to 0, the connection is weak or absent. If the value of the correlation coefficient between variables is above 0.70, then it is considered as high correlation. In this study, the correlation coefficient ranges from 0.71 to 0.83 (Table 2). This testifies that the objective indicators of image evaluation agrees well with the visual opinions.

The developed algorithms for improving the visual quality of digital images are integrated into the AutoImage program. This program received a certificate of state registration of a computer program (rights No. 30080 dated November 8, 2022).

The developed algorithms and software have been successfully tested, as evidenced by the acts of implementation of Timal Consulting Group LLP, BigForest IP, Kh.Dosmukhamedov Atyrau University, OIPII NAS of Belarus.

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