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IMPROVEMENT OF THE METHODOLOGY OF AUTOMATED DETERMINATION OF PHOTOMETRIC CHARACTERISTICS OF IMAGES BASED ON ROBUST AND NONPARAMETRIC METHODS

The article considers the current issues of improving the methodology of automated processing of measurement information registered in the form of images. Analysis of existing developments in the field of determining the statistical characteristics of images indicates a wide range of methods, for the justified application of which a preliminary analysis of experimental samples is required, which are sets of geometric and photometric characteristics of images obtained during the procedure of multiple measurements.

The results of a measurement experiment require obtaining not only quantitative values for individual geometric and photometric characteristics of images, but also an assessment of their accuracy and reliability. It is known that the assessment of the accuracy of the obtained experimental results of multiple measurements can be based on the standard procedure for assessing type A uncertainty or expanded uncertainty, while a necessary condition is to verify the hypothesis that the experimental sample complies with the model distribution law. If the hypothesis of compliance with the model distribution law is not confirmed, then it is necessary to apply robust and non-parametric methods of processing experimental data that are resistant to deviations from the form of the model distribution law.

The article outlines the sequence of development and the main operations of the method for processing experimental data in the form of corona gas discharge images.

An integral part of the method is an algorithm that allows using the measurement results obtained on the basis of multiple measurements as input data, ensuring the averaging of photometric parameters of images by calculating the sample median for each of the histogram brightness intervals and removing elements with significant deviations from the sample based on comparing the minimum and maximum elements with the median value of the corresponding histogram brightness range.

In addition to the robust method, which is based on median estimation, the developed method also provides for the use of series and sign criteria for comparative analysis of two parallel samples of similar photometric features of images; sign criterion – for samples of similar image characteristics in order to confirm their homogeneity during experimental study of samples of the same liquid under different conditions of the measurement experiment.

Key words: *information and measurement technology, robust methods, nonparametric methods, gas discharge radiation.*

Formulation of the problem. A characteristic feature of modern information and measurement technologies and automated environmental monitoring systems is the expansion of capabilities for registering values not only of individual physical quantities, but also the possibility of performing a comprehensive analysis of various types of measurement objects, which is based on the processing of visual data.

At the previous stages of development of automation of measurements and control of various objects and processes, the widespread implementation of information and measurement technologies based on the processing of experimental data in the form of visual information was limited by hardware for digital image registration, as well as limitations on the volume of transmission and storage of visual data.

In recent years, these limitations have actually been resolved thanks to achievements in the field of hardware for automation of information and measurement and computer-integrated technologies.

The processes of sustainable development of modern scientific research methodology, which are used at the empirical and theoretical levels of research, involve the processing and analysis of images, determine the need to improve methods for processing experimental data, taking into account the current level of development of software and hardware in the field of information and measurement technology.

Analysis of recent research and publications. The initial stage of processing experimental data recorded in the form of images is usually the so-called pre-processing of images, which includes various methods of image enhancement, image histogram correction, and noise removal [1-4]. At this stage, both universal methods and specialized methods of image processing of a certain type can be used. Methods of pre-processing of images are applied both in solving general problems of improving the quality of images in human visual perception, and as components of modern information and measuring technologies or machine vision technologies.

When using visual data in information and measurement technologies, for example, in environmental monitoring systems, the next stage of image processing will, typically include non-trivial image analysis procedures, the main purpose of which is to highlight such characteristic geometric and photometric characteristics that allow to qualitatively and quantitatively assess certain properties of the studied object or process.

The procedure for parameterizing images in the applied field, for example, in environmental monitoring, is usually based on the statistical analysis of samples of visual experimental data. In this case, standard procedures can be used that involve the use of parametric methods for processing experimental data with the assessment of such sample characteristics as the mean square deviation, experimental estimate of the variance, experimental estimate of the mean square deviation, and assessment of measurement uncertainty according to type A. In this case, the statistical analysis of images can be based on the model normal distribution law (Gaussian distribution) [5].

From the perspective of the applied use of visual experimental data in the field of metrology and information and measurement technologies, it should be emphasized that when determining the quality of the measurement result, estimates are indicated, for example, in the form of expanded measurement uncertainty, which involves the justified application of a certain model distribution law and, accordingly, performing a preliminary procedure for its identification, i.e. testing the hypothesis that the experimental sample does not contradict the model distribution law.

If experimental data in the form of images are used when developing information-measurement technology, the geometric and photometric characteristics of which correlate with the values of the parameters of the objects or processes under study, then the sets of these parameters (experimental samples) are subject to the procedure for testing the hypothesis for consistency with the model probability distribution law.

Unjustified application of the model distribution law, for example, when determining the coverage factor when calculating the expanded measurement uncertainty of geometric or photometric image parameters, can lead to errors in assessing the quality of measurements.

It should be noted that the use of the arithmetic mean or mid-range as the best estimate of the mathematical expectation also requires testing the hypothesis for consistency with the model of probability distribution law. For example, the presence of significant random deviations in the experimental sample can lead to a significant shift in the arithmetic mean.

These limitations and problems require analysis when using images as experimental data in the practical application of information and measurement technologies based on the statistical analysis of samples of geometric and photometric characteristics of images.

When detecting the regular occurrence of significant deviations among the samples of image parameters and the impossibility of confirming the hypothesis regarding the compliance of the samples with known model of distribution law (for example, normal, uniform, triangular), the methodology used in statistical analysis of images should be based on robust or nonparametric methods for processing experimental samples of measurement data.

Robust methods are recommended for processing experimental samples for which it was impossible to confirm the hypothesis of consistency with the model probability distribution law, or in cases of insufficient data or lack of a priori information about the distribution law [6, 7]. At the same time, the use of standard methods for processing experimental measurement data under the condition of unfounded assumption of the normal distribution law of the experimental sample can lead to significant errors in the obtained measurement results, assessment of their accuracy or omission of characteristics of the experimental data sample [8-10]. Also, in cases where it is impossible to confirm the assumption of the normal distribution law, it is recommended to use nonparametric methods [11].

Task statement. The analysis of modern methodology in the field of experimental data processing,

which are the results of the image parameterization procedure, indicates the need to improve information and measurement technologies based on statistical processing of experimental data samples. In particular, identifying cases when for experimental samples consisting of image parameters, it is impossible to confirm the hypothesis of consistency with a certain type of model distribution law or due to insufficient a priori data. The aim of the work is to improve the methodology for parameterization of geometric and photometric characteristics of gas-discharge radiation images with their subsequent statistical processing based on the application of robust and non-parametric methods of mathematical statistics.

Outline of the main material of the study. The need to use robust and nonparametric methods in the development of information-measurement technologies based on measurement information in the form of images may be due to the peculiarities of the image registration procedure, as well as the specificity of the research object and the physical processes that arise during the implementation of the measurement procedure. When using the corona gas discharge method in the field of developing environmental monitoring systems, the procedure for determining the characteristics of the liquid involves the impact of an external electromagnetic field on the liquid sample [12-14]. The measurement procedure consists in registering an image of the formation of gas discharges around the sample under study. In this case, the peculiarity of the measurement experiment is that the physical processes during the formation and propagation of gas discharges are probabilistic in nature. This causes the obtained image samples for identical liquid samples to always have a certain random variation of geometric and photometric characteristics.

During the analysis of a large number of experimental data obtained using the corona gas discharge method, it was found that the specificity of this method is the presence of deviations in the samples of experimental data, which consist of geometric and photometric characteristics of the images. Such deviations is due to the random nature of the formation of individual gas discharge tracks in the overall picture of the corona gas discharge, which is a superposition of many individual gas discharges. Thus, when using this method, the presence of deviations in the data samples is due to the physical nature of the formation of gas discharges.

The first modification of the method for processing gas-discharge radiation images involved the use of experimental estimates of the mathematical expectation of the number of pixels in the brightness intervals of image histograms in the form of an arithmetic mean value or median. This method was based on constructing a histogram of a gas-discharge radiation image from 256 columns corresponding to different brightness levels [15].

Further theoretical and experimental studies in the implementation of the corona gas discharge method for determining the characteristics of liquid-phase objects have proven the need to use methods based on the estimation of the sample median, in particular, the processing of data samples, which allowed obtaining statistical estimates that are more resistant to deviations among the photometric parameters of images due to the probabilistic nature of the formation of the gas discharge. On this basis, a methodology, algorithm and software were developed for constructing a histogram of images consisting of 12 columns, for each of which the median is estimated within the brightness interval [16-19], one of the modifications of the method based on the estimation of medians in terms of applied application for the analysis of corona gas discharge images of water of various types is presented in [20].

In [17], a detailed justification of the need to use robust methods for estimating statistical parameters of images, which are based on the median estimate of the corona discharge image parameters sample, rather than the arithmetic mean value, which is usually taken "by default", but turns out to be an unreliable experimental estimate of the mathematical expectation in cases where the hypothesis of compliance with the model normal distribution law is not confirmed on the basis of statistical criteria of agreement. Also in [17], a method for classifying images using the criterion of the minimum Euclidean distance between the medians of image histograms was proposed, the accuracy and reliability of which was confirmed on the basis of statistical processing of experimental samples of images of the corresponding typical water samples, with the volume of samples being no less than 400.

At the current stage of improving the method, algorithm and application software for analyzing gas-discharge radiation images, a universal algorithm has been developed that allows using the measurement results obtained on the basis of single or multiple types of measurements as input data with the possibility of averaging the photometric parameters of images of a sample of arbitrary size by calculating the sample median for each of the histogram brightness intervals. In this case, the condition of the available experimental sample size is checked and, provided that the number of elements is more than 30, the condition of deviation by 50% from the median

value for the current histogram brightness range for the minimum and maximum elements of the variation series is checked.

When the specified threshold level of deviation from the median is exceeded, the corresponding image is removed from the experimental data set, thus the number of elements of the variation series is reduced. The use of such an approach in improving the method for processing gas-discharge radiation images has ensured an increase in the robustness of the method due to effective automated censoring of the experimental sample of image parameters from random deviations caused by breakdowns from electrodes when creating a pulsed electromagnetic field, which appeared as zones of solid color of the inner circle of the image or corona of gas-discharge radiation.

The practical application of the universal algorithm for processing samples of arbitrary size is illustrated in Fig. 1-4, which present graphs of distribution histograms for selected typical water classes (shown in the figures by columns with solid gray color), together with the histograms, graphs of median values in the corresponding brightness intervals calculated for experimental samples of corona gas discharge images are shown (shown in the figures by solid black polygonal chains, while the ordinates of the points corresponding to the average values of the broken segments are equal to the calculated median values in the corresponding brightness intervals).

In the next step of improving the methodology for processing measurement information in the form of corona gas discharge images, in addition to robust methods for calculating the best experimental estimate of the mathematical expectation and censoring the experimental data sample, nonparametric methods for processing experimental data were applied, which are described in [21-24].

When using nonparametric statistical methods, the following tasks of processing experimental data, which are presented in the form of photometric features of corona gas discharge images, were solved: criteria of series and signs [21-24], which were used for quantitative comparative analysis of two parallel samples of similar photometric features of gas discharge radiation

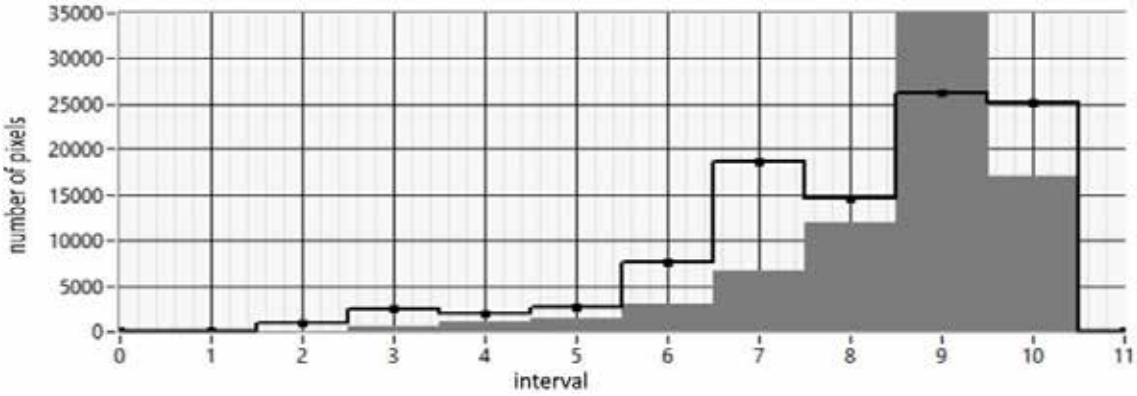

Fig. 1. Histogram graph of a distilled water samples and medians of corona discharge image brightness intervals for an experimental sample of images

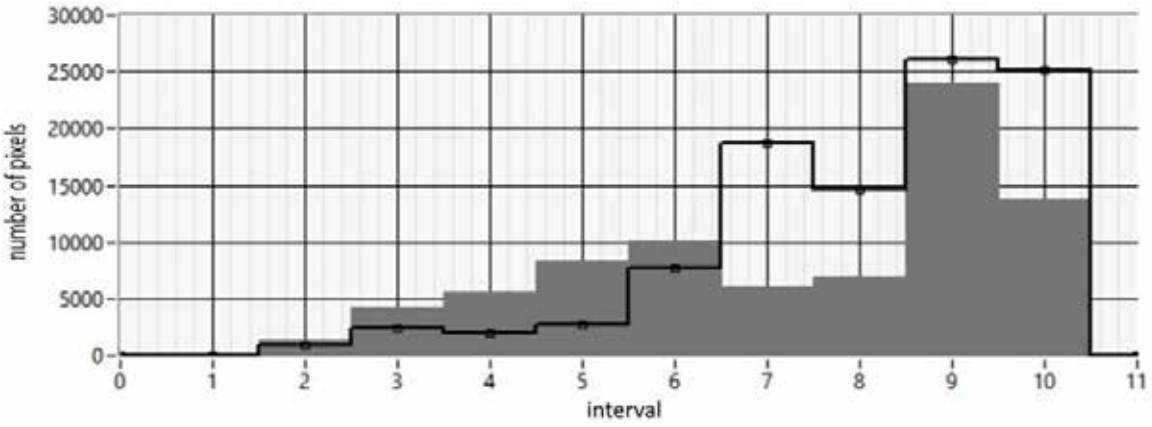

Fig. 2. Histogram plot of a tap water samples and medians of corona discharge image brightness intervals for the experimental sample of images

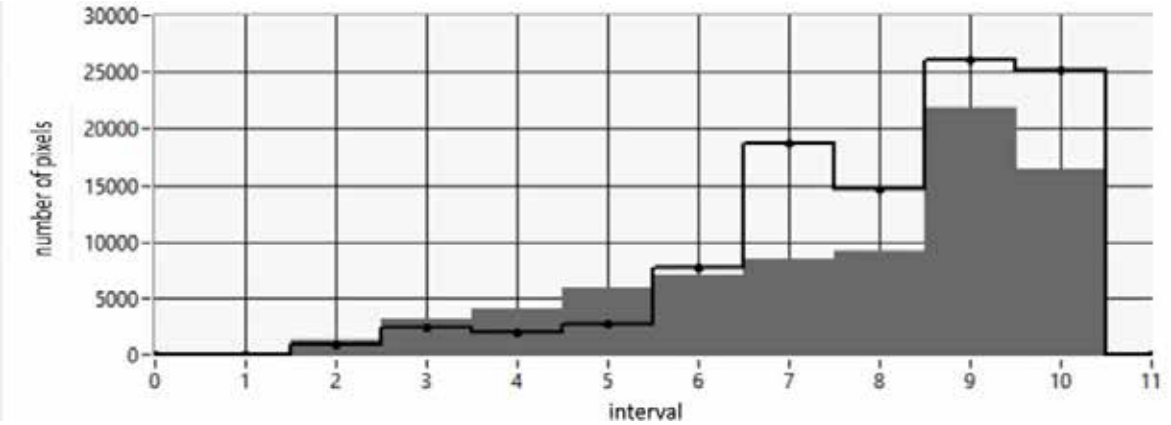

Fig. 3. Histogram plot of a natural water samples and medians of corona discharge image brightness intervals for an experimental sample of images

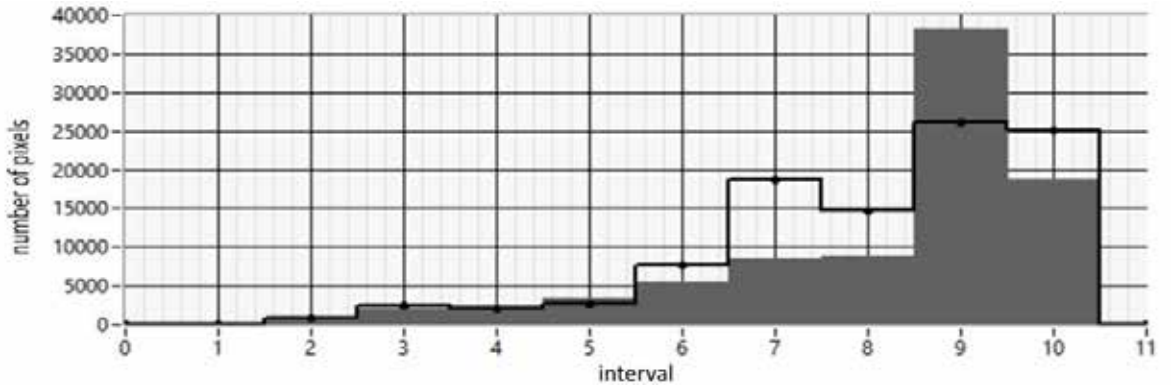

Fig. 4. Histogram graph of a functional water samples and medians of corona discharge image brightness intervals for an experimental sample of images

images; criterion of signs - in order to test the hypothesis of homogeneity for samples of similar characteristics of gas discharge radiation images to confirm their homogeneity during the experimental study of samples of the same liquid under different conditions of the measurement experiment.

Conclusions. The paper presents the results of scientific research performed with the aim of improving the methodology for automated determination of quantitative photometric parameters of images based on robust and nonparametric methods. The need to modify existing standard methods for processing measurement information, which is the result of multiple observations, was due to the specifics of the implementation of the gas-discharge radiation method and the physical processes that occur during the formation of a corona gas discharge pattern around a sample of the liquid under study during an active measurement experiment.

Based on the analysis of experimental data samples, it was proven that standard methods for processing the results of multiple observations, in particular those built on the basis of the assumption of consistency with the model normal distribution law, cannot be applied in this case due to the rejection of the relevant statistical hypotheses, as well as due to the presence of deviations in the experimental samples, due to the probabilistic nature of the formation of gas discharges, as well as the geometric complexity of the resulting figure as a superposition of individual tracks on the image of a corona gas discharge. Based on the conducted experimental studies, the effectiveness and reliability of the application of robust and non-parametric methods for processing experimental data samples, which are the results of parameterization of gas discharge radiation images, were proven.

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Глухова Н.В., Пісоцька Л.А. УДОСКОНАЛЕННЯ МЕТОДОЛОГІЇ АВТОМАТИЗОВАНОГО ВИЗНАЧЕННЯ ФОТОМЕТРИЧНИХ ХАРАКТЕРИСТИК ЗОБРАЖЕНЬ НА БАЗІ РОБАСТНИХ ТА НЕПАРАМЕТРИЧНИХ МЕТОДІВ

У статті розглянуто актуальні питання удосконалення методології автоматизованого опрацювання вимірювальної інформації, зареєстрованої у вигляді зображень. Аналіз існуючих розробок в галузі визначення статистичних характеристик зображень вказує на широкий спектр методів, для обгрунтованого застосування яких необхідний попередній аналіз експериментальних вибірок, які являють собою набори геометричних та фотометричних ознак зображень, отриманих в ході процедури багатократних вимірювань.

Результати проведення вимірювального експерименту вимагають отримання не тільки кількісних значень для окремих геометричних та фотометричних характеристик зображень, але й оцінки їх точності та достовірності. Відомо, що оцінка точності отриманих експериментальних результатів багатократних вимірювань може грунтуватись на стандартній процедурі оцінки невизначеності типу А або розширеної невизначеності, при цьому необхідною умовою є перевірка гіпотези про відповідність експериментальної вибірки модельному закону розподілу. Якщо гіпотезу про відповідність щодо модельного закону розподілу не підтверджено, то необхідно застосовувати робастні та непараметричні методи обробки експериментальних даних, які є стійкими до відхилень від форми модельного закону розподілу.

У статті викладено послідовність розробки та основні операції методики опрацювання експериментальних даних у вигляді зображень коронного газового розряду. Складовою частиною методики є алгоритм, який дозволяє у якості вхідних даних використовувати результати вимірювань, отримані на базі багатократних вимірювань, з забезпеченням усереднення фотометричних параметрів зображень шляхом обчислення вибіркової медіани для кожного з інтервалів яскравості гістограми та видалення з вибірки елементів з суттєвими викидами на підставі порівняння мінімального та максимального елементів зі значенням медіани відповідного діапазону яскравості гістограми.

Окрім робастного методу, який грунтується на оцінці медіани, розроблена методика передбачає також застосування критеріїв серій та знаків для здійснення порівняльного аналізу двох паралельних вибірок аналогічних фотометричних ознак зображень; критерій знаків – для вибірок аналогічних характеристик зображень з метою підтвердження їх однорідності в ході експериментального дослідження зразків однієї рідини в різних умовах вимірювального експерименту.

Ключові слова: *інформаційно-вимірювальна технологія, робастні методи, непараметричні методи, газорозрядне випромінювання.*

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