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METHODS FOR ASSESSING DIGITAL IMAGE QUALITY

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This article is devoted to developing a model for evaluating the quality of digital images. The problems of formalizing subjective expert statements to align them with objective metrics are highlighted. Image quality is considered a multifactorial system, and the necessity for the separate analysis of raster and vector graphics is indicated. The primary stage involves the formation of a set of influencing parameters by an expert group. It was established that the isolated consideration of individual characteristics is ineffective due to their interdependence. The apparatus of semantic networks was utilized for the visualization and formalization description of these relationships. The network nodes correspond to factors, and the arcs represent atomic predicates of relations. Since the intensity of the influence of various factors is unequal, a ranking method was applied. It considers the hierarchical relationships of the first and second levels of reachability by assigning positive or negative weight coefficients. The subsequent step involved using pairwise comparison matrices based on the Saaty scale. This allowed for a quantitative assessment of the superiority of certain parameters over others in the absence of exact numerical data. The complexity of the evaluation process and the presence of uncertainty necessitated the use of fuzzy logic. Subjective expert judgments were transformed into linguistic variables. A comprehensive logical inference model was developed, including a fuzzification stage to transition to fuzzy sets based on membership functions. A knowledge base of "if-then" fuzzy rules integrating multiple parameters was formed. Defuzzification is performed using the center of gravity method to obtain a crisp numerical value. The main result is a generalized model for determining the integral quality indicator. The proposed methodology formalizes the interconnections between factors and minimizes subjectivity. The created model serves as a foundation for automating the quality control of graphic content.

Keywords: *image, factor, fuzzification, defuzzification, fuzzy logic, model, semantic network, ranking, hierarchy, information technology.*

Problem Statement. Digital image quality plays a crucial role in the publishing and printing industry. The complexity of image quality assessment lies in the necessity to simultaneously account for objective technical parameters and subjective human perception. Consequently, developing models and information technologies capable of ensuring a comprehensive evaluation of digital image quality under conditions of uncertainty and multifactoriality constitutes a highly relevant scientific challenge.

Analysis of Recent Research and Publications. In the context of developing digital technologies, automated digital image quality assessment is important for medical diagnostics, remote sensing, and machine vision systems. The main problem lies in bridging the gap between the subjective impressions of experts and objective mathematical metrics. Since the visual inspection of large data arrays by a human is resource-intensive, it is necessary to develop algorithms capable of mathematically emulating human perception.

The relevance of automation is confirmed by modern research. For instance, [1] emphasizes that although the expert assessment of MRI images is the most accurate, it consumes too much of doctors' time. At the same time, research [2] proves that classical objective metrics (e.g., PSNR or SSIM) often do not correlate with actual visual perception. This requires the creation of combined multifactorial indices. Furthermore, to formalize qualitative characteristics under conditions of uncertainty, combining fuzzy logic and the analytic hierarchy process is highly relevant [3].

Despite significant scientific interest, the task of creating a digital image quality assessment model that integrates semantic modeling, factor analysis, and fuzzy logical inference for the comprehensive evaluation of raster and vector images remains not fully resolved.

Purpose of the article. The purpose of the article is to develop a digital image quality assessment model based on the integration of semantic modeling, factor analysis, and fuzzy logic methods.

Presentation of the main research material. The problem of assessing digital image quality lies in the difficulty of formalizing subjective impressions and the necessity of aligning them with objective metric characteristics. That is, the quality of digital images is not a constant value. It is formed as a result of the complex interaction of a significant number of parameters. Each of them can degrade or improve the quality, and the cumulative effect determines the final impression. In light of the above, the following assertion is valid [4].

Assertion 1. There is a certain set of factors that influences the quality of digital images.

The multifactorial nature of image formation processes necessitates the combination of various methods and tools into a single information technology aimed at determining an integral quality indicator. It is advisable to consider digital images as two separate types — raster and vector — which is associated with significant differences in their creation and representation.

The initial stage of the research involved forming sets of factors influencing the quality of raster or vector images. That is, there is a certain set X, which includes the factors $X_1, X_2, ..., X_n$, formed based on expert evaluation. The expert group was formed from specialists knowledgeable in the investigated subject area [5].

Assertion 2. Interconnections exist between the factors of digital image quality.

The existence of interdependencies between factors is a regular property. The investigation of digital image quality cannot be reduced to the isolated analysis of individual factors. It requires a systematic approach and the consideration of interrelationships. This enables the subsequent description of quality as an integral characteristic. For example, color depth affects the accuracy of shade reproduction depending on the chosen color space. Therefore, identifying the interdependencies between individual factors is an important task. An effective method for visualizing the dependencies between factors is modeling via semantic networks. The fundamental idea is to represent knowledge in the form of nodes and arcs with atomic predicates [6]:

$$S = (X, E, P), \quad (1)$$

where X is the set of nodes (factors), E is the set of arcs (relations between factors), and P represents atomic predicates (description of connections).

In the process of expanding knowledge in the subject area, it is possible to add new nodes and relations without destroying the overall structure.

Assertion 3. The quality of the investigated process is formed under the action of factors with varying degrees of influence.

There are no absolutely identical factors; therefore, their influence also varies. Accordingly, it is possible to determine the intensity of this influence, that is, the significance of the factors. Factors with the greatest influence are the most significant among the factors of the analyzed set.

The ranking method allows determining the ranks and priorities of factors based on information about the number of influences and dependencies of the 1st and 2nd levels of reachability. The initial stage involved developing hierarchical models of the connections for each factor. Subsequently, the ranking of factor weights was performed. Considering the weight difference between the levels of reachability was essential. This was realized by assigning different weight coefficients. Herein, positive weights were used for direct influences, while negative ones were applied to dependencies. The obtained data served as the basis for developing the factor significance model [7].

To account for the values of the verbal descriptions of the semantic model's connections, it is advisable to introduce amplification coefficients. Then, the arc E_i, connecting the pair of factors $\left(X_i, X_j\right)$ and having the weight w_{ij} indicates the exertion of influence by factor X_i on factor X_j with a certain intensity. Thus, verbal descriptions receive a numerical interpretation.

Assertion 4. The comparison of factor pairs allows for a quantitative assessment of the degree of superiority of one factor over another.

Therefore, the further improvement of the model involved the application of the analytic hierarchy process based on pairwise comparisons. A specific feature is the possibility of evaluation even in the absence of quantitative characteristics of the factors, that is, when the information has a qualitative or expert nature. The factors were sequentially compared with each other, forming a pairwise comparison matrix. Each matrix element a_{ij} reflects the importance ratio between factors A_i and A_j. That is, the i-th row contains generalized information about the relative significance level of factor A_i with respect to the other elements of the set. Obviously, the diagonal elements of the matrix take a fixed value of 1. In this context, the use of the Saaty comparison scale was an effective approach for expressing preferences [8, 9].

Assertion 5. A set of variables represented by verbal terms can be used to describe complex systems.

Complex systems are characterized by multifactoriality, nonlinearity, and the presence of a significant degree of uncertainty. In such conditions, numerical parameters are not always capable of fully reflecting the essence of the phenomenon. For example, assessments such as “high level of quality” or “low contrast” are difficult to formalize using precise numbers.

The use of linguistic variables — variables represented by verbal terms — allows for the integration of expert knowledge and subjective judgments into mathematical models. Linguistic variables form the basis of fuzzy logic. The set of all possible values of a linguistic variable constitutes its term set. Theoretically, it can contain an unlimited number of elements, but in practice, it is always finite.

Assertions 1–5 substantiate the expediency of applying the principles of fuzzy logic to assess the quality of digital images. The main procedures of fuzzy logic are fuzzification and defuzzification. Fuzzification is intended for transforming crisp data into fuzzy sets. That is, each parameter receives a degree of membership in a certain category through the processing of membership functions. The subsequent formalization of knowledge was carried out using fuzzy knowledge bases and logical equations. Structurally, fuzzy rules have the following form [10]:

$$IF\ x \in N, THEN\ y \in M \ , \tag{2}$$

where x is the input variable described by the fuzzy set N, and y is the input variable described by the fuzzy set M.

The membership functions $\mu_N(x)$ and $\mu_M(y)$ determine the degree of truth of statement (2). Consequently, the system of fuzzy rules is formed as a collection of similar statements that combine various linguistic variables. It can take the following form: if the contrast is low, then the quality is low; if the contrast is medium, then the quality is medium; if the contrast is high, then the quality is high. However, in multifactorial systems, fuzzy rules allow for the simultaneous integration of several input parameters: if the resolution is high and the contrast is high, then the image quality is high. A fuzzy rule for two input parameters [5, 10]:

$$IF\ x \in N\ AND\ z \in C, THEN\ y \in M \ , \tag{3}$$

where z is the input variable described by the fuzzy set C.

Rules for a larger number of parameters are written following a similar principle. The system of fuzzy rules forms a knowledge base. A logical continuation is the development of fuzzy equations [10].

Defuzzification provides the reverse transformation; that is, specific numerical data are obtained based on fuzzy sets. Among the existing methods, the center of gravity method is the most common. The essence of the method lies in determining the equilibrium point for the membership function of the output variable. The advantages of this method are: the stability of the results due to the consideration of all possible values of the output variable; the intuitive clarity of the results; and its suitability for use in multifactorial models [5, 10].

Considering the provided information and justifications, a generalized model for investigating the digital image quality assessment process was developed (Figure 1).

Thus, the formation of digital image quality is appropriately considered as a complex multifactorial process. Resolving the problem of quality assessment requires a systematic approach, factor analysis, and the application of fuzzy logic methods. The proposed methodology provides an opportunity for the formalized description of the interconnections between factors, considering the uncertainty and variability of the input data. The development of an information technology for assessing digital image quality will allow for taking into account the significance of the influence of key factors and obtaining an integral quality indicator based on the selected parameters.

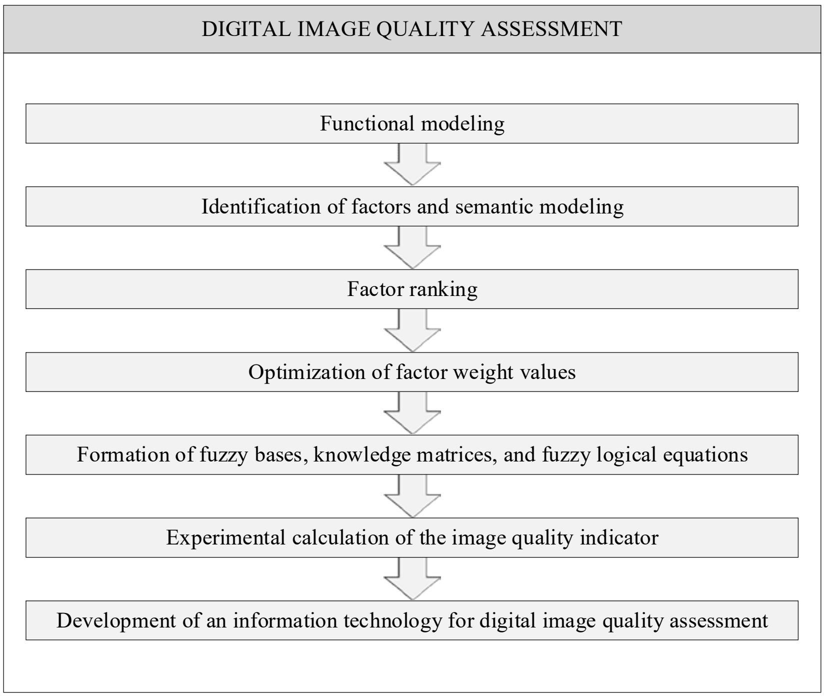

Figure 1. Model of the digital image quality assessment process

Conclusions. As a result of the conducted research, it was substantiated that assessing digital image quality is a complex multifactorial process. It requires a systematic approach and the combination of objective metrics with subjective expert judgments. The expediency of dividing factors into groups for raster and vector images was proven. It was established that it is advisable to use semantic networks for the visualization and mathematical description of the interdependencies between factors. To determine the weight coefficients, the application of the ranking method and pairwise comparison matrices was justified. This allows for a quantitative assessment of the degree of superiority of certain parameters over others and minimizes subjectivity. The effectiveness of the fuzzy logic apparatus for describing complex systems using linguistic variables was also proven. The procedures of fuzzification, the formation of fuzzy knowledge bases, and defuzzification using the center of gravity method to obtain a crisp integral indicator were described. The outcome was the development of a generalized model of the assessment process, which integrates factor analysis, semantic modeling, and fuzzy inference into a single information technology.

Prospects for further research lie in the practical implementation of the proposed model: developing specific term sets for linguistic variables, constructing comprehensive fuzzy knowledge bases, and the software implementation of the defuzzification algorithm for the automated calculation of the integral image quality index in real time.

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МЕТОДИ ОЦІНЮВАННЯ ЯКОСТІ ЦИФРОВИХ ЗОБРАЖЕНЬ

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Запропоновано моделі оцінювання якості цифрових зображень. Означено проблеми формалізації суб'єктивних тверджень експертів для їх узгодження з об'єктивними метриками. Якість зображення розглядається як багатофакторна система. Вказано на доцільність окремого аналізу растрової та векторної графіки. При цьому, первинним етапом є формування експертною групою множини параметрів впливу. Встановлено, що ізольований розгляд окремих характеристик є неефективним через їх взаємозалежність. Для візуалізації та формалізації опису цих зв'язків використано апарат семантичних мереж. Вузли мережі відповідають факторам, а дуги — атомарним предикатам відношень. Оскільки інтенсивність впливу різних чинників неоднакова, застосовано метод ранжування. Він враховує ієрархічні зв'язки першого та другого рівнів досяжності з присвоєнням додатних або від'ємних вагових коефіцієнтів. Наступним кроком є використання матриць попарних порівнянь за шкалою Сааті. Це дає можливість кількісно оцінити перевагу одних параметрів над іншими за відсутності точних числових даних. Складність процесу оцінювання та наявність невизначеності зумовили використання нечіткої логіки. Суб'єктивні експертні судження трансформовано у лінгвістичні змінні. Розроблено комплексну модель логічного виведення. Вона включає етап фазифікації для переходу до нечітких множин на основі функцій належності. Сформовано базу знань із нечітких правил «якщо-тоді», що інтегрує множинні параметри. Дефазифікація здійснюється методом центру ваги для отримання чіткого числового значення. Головним результатом є узагальнена модель визначення інтегрального показника якості. Методика формалізує *взаємозв'язки між чинниками та мінімізує суб'єктивізм. Створена модель є підґрунтям для автоматизації контролю якості графічного контенту.*

Ключові слова: *зображення, фактор, фазифікація, дефазифікація, нечітка логіка, модель, семантична мережа, ранжування, ієрархія, інформаційна технологія.*

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