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FORMING A METHOD FOR THE INTEGRAL ESTIMATION OF INTERFACE QUALITY IN AUTOMATED SYSTEMS BASED ON THE QUANTITATIVE AND QUALITATIVE INDICATORS

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Informatization is considered an integral part of the functioning of the present-day society, which changes the nature of human-computer interaction and interface. It was substantiated that the interface quality determines the success of software marketing. It was shown that quality is estimated by both quantitative and qualitative indicators. Their calculation is complicated because of the lack of an analytical model of usability. Two Euclidean norms in the form of the root mean square value and the largest value of the modulus of the set of attribute values were proposed for continuous factor attributes. The problem was reduced to a geometric inequality by applying development into the Maclaurin series and a three-level comparator. Expressions of the upper and lower boundaries of the generalized index of interface quality represented through a set of attribute estimates were obtained. Expressions of the maximum possible absolute and relative errors represented by the method of recurrent approximation through the first and second derivative of the trend were substantiated. Representation of data in a plane with one common axis turned by a certain angle was applied which enabled fast viewing of all planes. It was shown that when all attributes have a quantitative dimension, it is sufficient to apply one norm to estimate the generalized index. However, in the case of quantitative and qualitative estimations, consecutive application of norms for the root mean square and the maximum possible value of the module solves the problem of comprehensive generalized estimation of interface quality. Experimental study of estimation of the generalized quality of the user interfaces for the MedInfoService medical information system which covers automation of curative treatment processes in outpatient clinics and hospitals was presented

Keywords: software interface, generalized estimation, Euclidean norms, quantitative and qualitative attributes, spatial-planar trend

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1. Introduction

Informatization as an integral part and means of functioning covers more and more areas of human activity. In this regard, the nature of the interaction as an attribute of coexistence acquires an essential transformation. Human-computer interaction becomes decisive as an element of bilateral active-passive exchange and complementarity. Regardless of the type of activity from a simple search in the network to control in complex automated systems of robotic production, the interface is an element of information exchange and interaction. Quality of software interface and availability of methods for its differential and integral estimation becomes the prerequisite determining the level of capabilities, quality of interaction and integration. Thus, commercial success or failure of new software depends on existing user interface problems. For example, complexity or non-obviousness of actions or lack of the system response to the user's actions causes a negative reaction. Suffice it to mention the interface of the operating system MS Windows 8/8.1 (USA) in a form of tiles. Its example shows how manufacturers' attempts to create a universal interface for PCs and mobile devices, on the contrary, have repelled users. Labor costs for changes in the functional structure to ensure simplicity and convenience of the user's work – such was a payoff for insufficient attention to the user interface.

Thus, the usability concept was formed in scientific literature as a consequence of the importance of the user interface. With the help of the latter, the overall degree of usability of the software interface is estimated [1]. There is a similar term "ergonomics", but it has a different area of spread and differs in nuances of definition [2, 3]. Usability as a concept is applied exclusively to software interfaces of applications of devices for diagnostics, displaying processes in digital oscilloscopes and computer technology and determines concepts of their development focusing on maximum psychological and aesthetic convenience for the user.

Thus, according to [1–3], the user interface, as an interactive system component, provides information and controls that the user needs to perform specific tasks with the system. However, the user perceives and forms an idea of software as a whole through the interface, so presentation of the interface role and its estimation as a component of an interactive system is given based on various criteria. In this regard, there are several types of estimation of the user interface quality which represent it by both quantitative and qualitative (verbal) indicators. Today, testing as one of the mandatory components of the life cycle of any software does not end with the definition of integral indicators of interface quality because of the lack of an integral estimation method and a method of combining results of quantitative and qualitative estimates. In this regard, the formulation and solution of the problem of quantitative integral estimation of an interface according to quantitative and qualitative attributes of any software becomes a necessary part of the life cycle. Its solution ensures the success of software promotion estimation in the market, which substantiates the relevance of this scientific and applied problematics.

2. Literature review and problem statement

At present, literature sources [1] and standards [2, 3] define several lines of estimation of user interface quality. First of all, it is a quantitative approach [1]. To estimate an interface, a number of actions, degree of work completeness, time spent on work execution, number of errors, and user requests to the Help option are measured [1]. The advantages of such methods include reliable results obtained as a practical estimation by the criterion of truthfulness and which can be displayed by target user groups [1].

Qualitative indicators: comprehensibility and ease of perception of the software, subjective perception of the software interface, the atmosphere of psychological comfort or discomfort that accompanies work with the software are also used for estimation. In this case, the estimation process is usually proposed to organize as such that is accompanied by the openness of the test content and subsequent discussion with users of their results and impressions [4]. In terms of time to estimate the interface quality, several approaches were also proposed [5, 6]. It was proposed to estimate the quality of the user interface in the process of software development when the interface is estimated at each stage and corrected to achieve better usability [5]. On the other hand, usability is estimated to validate the interface of a finished software product according to predefined parameters [6]. Beside different views on the very concept of usability, there are different approaches to the estimation of the software interface quality [7–9]. For example, it was proposed in [7] to use an expert report as a form of specialist estimation without taking into account the opinion of the end-user. On the contrary, another approach implies a product release for early access and then appropriate changes are introduced according to comments and wishes of users [7]. There are also analytical and empirical approaches [8]. One of them is based on the analysis of software or patterns of user interaction with the program interface. Another approach is based on the actual usability of the software product [8]. There is also an approach based on a combination of different approaches for the best and most complete estimation of software interface quality [9].

Thus, these methods solve local problems [10] and apply user-friendly but heterogeneous estimation procedures [11] when developers can evaluate only part of parameters: quantitative or qualitative [12]. Data on estimation results are presented using undefined metrics which makes it impossible to bring them to a common metric. In addition, it should be noted that the lack of a common analytical model of software usability makes it impossible to verify its reliability on the basis of empirical indicators of the same group [13]. Summary of shortcomings and problems identified in [10–13] requires generalization and solution. The first of the major unresolved issues implies the formation of a unified metric for estimation of a generalized index according to attributes differing by their nature and the relationship of their relative errors with an estimate of the maximum possible error. In addition, complexity in combining quantitative and qualitative indicators of the interface [14] and their integral estimation [15] were defined as the problems that remain unsolved until now. An attempt was made in [16] to conduct estimation not based on a list of questions, review, or visual passage through all interface options but on the basis of the formation of rules of definition. The proposed method generates rules of estimation as a mono-objective technology aimed at maximization of the mobile interface quality. Study [16] is an example of an approach that has improved four applications for Android devices with more than 70 % accuracy and repeatability. The flourishing presence of web applications and excessive influence of social media increases the need for greater interconnection of application interfaces and exchange and presence on the Internet [17]. This allows smartphones and gadgets to become a "mainstream" as demonstrated by the example of Malaysia. Study [17] shows how a national program provides and supports the development of mobile applications aimed at bringing the Malaysian web and mobile application industry to global standards. It also highlights practice and education focused on the implementation of the interface of user-oriented mobile applications [17]. Information accessibility is a major problem in our society [18]. The paper shows that information technologies are always one step ahead. New devices appear before the problem of accessibility is solved for elderly people and people with disabilities. The latter are not the only users who are excluded from the information exchange technologies [18]. These issues are even harder to solve with new devices, such as mobile phones and tablets, where there is no proper set of guidelines targeted to this domain. In addition, [18] identifies a set of necessary options for an appropriate level of accessibility of elderly people's interfaces which is proposed on the basis of literature analysis. Results of the proposed accessibility checklist for elderly people that have been proposed are important for further rethinking and practical work. A survey of three mobile applications on the Android platform is aimed to change the default interface to a more accessible one [18]. Certainly, the list of studies analyzed there does not cover the entire list of studies devoted to the problems of interface development. However, they allow us to identify the main feature inherent in the current state of development of methods for assessing the interface quality. Quality of the interface as an integral index determines a set of both quantitative and qualitative features whose magnitude is influenced by subjective and random factors and events. Thus, the namely simultaneous presence of quantitative and qualitative estimates of features is the second unsolved problem for the formation of a method of integral assessment of the interface quality index and needs its solution. Therefore, the determination of such quantities will always be accompanied by a requirement of determining reliability. One of the approaches to verify the reliability of the obtained results of the assessment of software quality in general is the use of methods of interval mathematics which makes it possible to limit the interval of finding a solution by guaranteed scopes. However, the wide range of uncertainty of initial data influences the error of the result. In this regard, the scope of the resulting interval was limited in [19] as one of the approaches chosen to reduce the degree of error and take into account the experience and skills of users who interact with software. It is very difficult to take into account all needs of users when creating an interface for working with the software. For example, study [20] considered a model of an adaptive user interface, which dynamically changes from the beginner user interface to the experienced user interface. Thus, user productivity can be increased if the characteristics of the software interface correspond to the level of the user's skills. Other cases that demonstrate the implementation of the principle of adaptation to the level of the user skills and the problem complexity are considered in [21] on examples of numerical analysis of mathematical problems. As a result of the analysis of studies on estimation of the quality of the user software interface, the following was found. First, let us define the concept of a generalized index of interface quality: usability or a generalized quality index as defined by four features. Secondly, highlight the following features that will describe usability, i. e. attractiveness for the software interface user [22]:

– intelligibility or ease of learning. Under the ease of learning, we understand the threshold of user entry to work with software. This parameter is affected by the time of the user familiarization with the software to perform a concrete task. This is the ratio of the number of operations performed correctly and which the user considers correct to the number of operations performed in total before completion of the list of actions to perform the interface function;

– labor intensity: the number of basic operations to perform tasks with the use of interface (or its derivative: working speed). By speed we mean the number of basic operations, such as mouse movement, pressing keyboard keys, etc., to perform a concrete task per unit time;

– rate of errors occurring when working with the user interface. Under the error rate we will consider a relative value equal to the ratio of the number of errors to the total number of actions, e.g. ratio of the number of keyboard keys that were incorrectly pressed to the total number of actions;

– subjective satisfaction with working with the user interface. Under the subjective satisfaction of the user, we will consider the presence of a sense of satisfaction when working with the software interface or absence of a state of psychological discomfort when performing a certain task.

Analysis of the above studies allows us to state that the main unsolved problem consists in the construction of a method of integral estimation of an index of quality of the software interface based on estimates of quantitative and qualitative attributes. Besides, the lack of a known law of connection between quantitative and qualitative data of different attributes, as well as a lack of numerical data complicate the solution of this problem. Lack of a standard that formulates a single list of actions, which is formalized as mathematical operations, is an additional reason for formulating the problem of forming a method of assessing the generalized index of software interface quality.

3. The aim and objectives of the study

The study objective is to improve the efficiency of estimating the quality of the software interface by the development of a method of forming an integral (generalized) index as an information model based on estimates of quantitative and qualitative attributes.

To achieve this objective, the following tasks were set:

– investigate the applicability of a unified metric to estimate a generalized index of quality according to the idea of using a three-level comparator and establish properties of the relative error for the formed trend;

– investigate the applicability of a unified metric to the synthesis of the trend of the generalized index of quality according to the idea of spatial representation with rotating coordinate planes for quantitative and qualitative indicators;

– conduct experimental tests of integral estimation of the user interface on the example of the MedInfoService medical information system covering automation of curative processes in outpatient clinics and hospitals for medical statistical reporting.

4. Solving the problem of generalized estimation of the interface quality index

4. 1. Construction of a trend of a generalized index of interface quality

Let us denote attribute estimates by indicators X_i, $i=\overline{1,4}$. Taking into account heterogeneity of the index content, assume that there exists its own non-zero quantity $|X_i|_{\max}$ for each i-th series. Assume that X_i is the quantity integrated with a square in the interval of its definition and introduce the norm:

$$\|X_i\| = \frac{1}{|X_i|_{\max}} \sqrt{\int_0^{|X_i|_{\max}} X_i^2 \mathrm{d}X_i}. \quad (1)$$

Assume that there is a continuous function and denote it by $|\mathrm{QUI}|_{\max}$ where QUI (Quality of the User Interface) means an integral index of quality of the user interface. Unlike [23], a three-level comparator can be used for each estimate:

$$c_i = \begin{cases} 1, \forall x_i, & \text{if } 0 < x_i \le x_{\max} \\ & \text{satisfies the } i\text{-th criterion.} \\ 0 \forall x_i, & \text{if } x_i = 0 \\ & \text{does not satisfy the } i\text{-th criterion,} \\ -1 \forall x_i, & \text{if } -x_{\max} \le x_i < 0 \\ & \text{satisfies the } i\text{-th criterion.} \end{cases} \quad (2)$$

Introduce a purely formal notation of the integral index as a function:

$$\mathrm{QUI} = f\left(\mathrm{c}_1 x_1, \mathrm{c}_2 x_2, \mathrm{c}_3 x_3, \mathrm{c}_4 x_4\right),$$

where $|c_i x_i| \le |x_i|_{\max}$ and weight coefficients that provide scaling of the quantities:

$$\omega_i = \frac{x_i}{\sum x_i}; \quad \sum \omega_i = 1.$$

Define axiomatic conditions which are clear, but are the preconditions necessary for further strict statement and substantiation:

$\forall x_i = 0$ overall figure $QUI = 0$;

$\forall x_i < |x_i|_{\max} \rightarrow QUI < |QUI|_{\max}$:

if all $x_i = |x_i|_{\max} \rightarrow QUI = |QUI|_{\max}$.

In what follows, the quality of interfaces will be considered within these definitions and assumptions. Decompose the function that determines integral exponent into the Maclaurin series as follows [24]:

$$\mathrm{QUI} = \sum_{i=1}^{N} \frac{\partial \mathrm{QUI}}{\partial x_i}\Big|_{x_i=0} c_i \Delta x_i = = \sum_{i=1}^{N} \frac{\partial \mathrm{QUI}}{\partial x_i}\Big|_{x_i=0} c_i x_i = C \sum_{i=1}^{N} \delta_i x_i; \quad (3)$$

$$C = \sum_{i=1}^{N} \frac{\partial \mathrm{QUI}}{\partial x_i}\Big|_{x_i=0}; \quad \delta_i = C^{-1} \frac{\partial \mathrm{QUI}}{\partial x_i}\Bigg|_{x_i=0} c_i.$$

Estimate the lower limit of the interface quality according to the properties of geometric inequality:

$$\mathrm{QUI} = C \sum_{i=1}^{N} \delta_i x_i \geq C \prod_{i=1}^{N} (x_i)^{\delta_i}.$$

If the influence of all factors is considered to be equivalent, then the lower limit of the interface quality can be estimated as:

$$\sum_{i=1}^{N} \frac{|x_i|^N}{N} \geq \prod_{i=1}^{N} x_i. \quad (4)$$

For a case when the influence of various factors is determined by weight coefficients, the smallest value of the interface quality can be estimated taking into account properties of geometric inequality as follows [24]:

$$\frac{1}{N} \sum_{i=1}^{N} |x_i|^N \geq \left(\prod_{i=1}^{N} \left(\frac{|x_i|}{\omega_i^{1/N}} \right)^{\omega_i} \right).$$

The resulting expression gives boundaries of the interface quality to the nearest multiplier:

$$\prod_{i=1}^{N} x_i \leq \mathrm{QUI} \leq N \prod_{i=1}^{N} x_i.$$

Thus, the tool for estimation of the top and bottom boundaries of the interface quality was substantiated based on the introduced norm, determined weight coefficients, and properties of geometric inequality. At the next step, introduce estimation of errors of the interface quality attributes as ε_i. According to the generally defined approaches, absolute ΔQUI, or relative error, is estimated as a sum of values of the maximum possible absolute or relative errors, respectively [25]:

$$\Delta\mathrm{QUI} = \mathrm{QUI} \sum_{i=1}^{N} \left| \frac{\Delta x_i}{x_i} \right|, \quad (5)$$

but because $|\varepsilon_i| = \left| \frac{\Delta x_i}{x_i} \right|$, then

$$\Delta\mathrm{QUI} = \mathrm{QUI} \sum_{i=1}^{N} |\varepsilon_i|.$$

Thus, a quantity was obtained that estimates interval of maximum possible deviation from the average value of the generalized quality index playing the role of interval in the estimation of data reliability.

4. 2. Applicability of the unified metric to the synthesis of the trend of the generalized quality index of quantitative and qualitative estimates

The maximum error value is determined by a sum of absolute values of relative errors. At the next step, determine the influence of the size of the averaged interval and properties of the integral index of QUI. Let us present the type of dependence of the QUI index on the number of interface requests and establish its effect on the local amount of the error. To do this, use a quadratic form of estimation in a series of development by the method of recurrent approximation, as proposed in [24], in the vicinity of request u_0:

$$\Delta\mathrm{QUI} = = \left(\mathrm{QUI}_0 + \sum_{i=1}^{N} \frac{\partial \mathrm{QUI}}{\partial x_i} \frac{\mathrm{d}x_i}{\mathrm{d}u}\Big|_{u_0} \Delta u + + \sum_{i,j=1}^{N} \frac{\partial^2 \mathrm{QUI}}{2\partial x_j \partial x_i} \frac{\mathrm{d}x_j dx_i}{\mathrm{d}u^2}\Big|_{u_0} \Delta u^2 \right) \times \times \sum_{i=1}^{N} \left(\varepsilon_{i_0} + \frac{\mathrm{d}\varepsilon_i}{\mathrm{d}u}\Bigg|_{u_0} \Delta u + \frac{\mathrm{d}^2\varepsilon_i}{2\mathrm{d}u^2}\Big|_{u_0} \Delta u^2 \right).$$

Note that the averaging interval and properties of the integral index of QUI allow the establishment of a relationship between interval dimensions and changes in the first and second derivatives of a generalized series of interface requests and the allowable error ΔQUI of the integral index. For practical reasons, assume that the number of requests is a continuous quantity u and there is an integral of the squared error. Choose an interval of width δτ and introduce the norm by analogy with the definition (1):

$$\|\Delta\mathrm{QUI}\| = (\delta\tau)^{-1} \sqrt{\int_{u_0-\frac{\delta\tau}{2}}^{u_0+\frac{\delta\tau}{2}} \Delta\mathrm{QUI}^2 \mathrm{d}u}.$$

To implement the approach to the construction of adequate models [25] summarizing the set of four series of data, apply the normalization of indicators. In addition, to find a simple, convenient and at the same time clear representation of the quality index (generalized estimate of software quality) and its components and especially their trends, use representation in a three-dimensional space of planes. These planes intersect behind one line, the location of which allows rotation around it as a common axis [24]. Assume that there is a common physical quantity characteristic of all attributes. Assume it makes it possible to analyze and evaluate signs at its fixed value. Without considering its content, assume only that it exists, is continuous, has a quantitative dimension, and is an ordered set. Under these assumptions and conditions, introduce axis of this attribute, e.g. axis of the number of interface requests for a set of four factors. Under these conditions, a general expression for the n-th index ranging from $-|x_i|_{\max}$ to $|x_i|_{\max}$, as a series of data for mapping to the plane, after multiplication by the factor $\exp(\pi ni/2)$ will be represented on the plane turned by angle $(\pi/2)n$. Represent transformations for the other three factors similarly on three planes in which changes of one-factor attributes are mapped as functions of a common physical quantity fixed for them. Based on the fact of the existence of lower and upper boundaries of estimates in conventional units set by users, choose one of the possible Euclidean norms. In the case when all attributes are quantitative, the application of norm (1) leads to undefined but different intervals of values. The latter, in principle, does not prevent the graphical presentation of information and the formation of a generalized estimate. However, in the presence of quantitative and qualitative estimates, the range of values is very important because the membership function for normal fuzzy sets varies in a limited range from zero to one. Consecutive application of the norm of the root mean square value in the interval according to (1) and then the second norm of the maximum possible value of the module provides a single interval of determination. This norming of qualitative and quantitative factors reduces the problem of generalized estimation of software interface quality to the problem of determining the modulus of the vector by its components.

4. 3. Experimental study of the suitability of the method of generalized estimation of interface quality for practical implementation

To verify the validity of the method of generalized estimation, conduct a study of the quality of the user interface of the MedInfoService medical information system (version 4.2.0 developed by Technoinfomed-2 PE, Ukraine). Currently, it is a tool for automating curative processes in outpatient clinics and day hospitals. This system also generates medical statistical reporting. The MedInfoService system was accredited by the Ministry of Health and connected to the E-Health electronic health care system. The following indicators were introduced for the experiment: clarity; the speed of solving problems; the rate of errors when working with the user interface; subjective satisfaction from working with the user interface. The respondents were second-year students of the Faculty of Computer Science in the discipline Quality of Software and Testing. During the experiment, respondents were asked to perform by request ten identical operations in a strict sequence (hereinafter referred to as *N*). When performing each operation, the respondent recorded values of four parameters: use of prompts when performing operations; task execution time; the number of errors made by the respondent in performing the task; whether the result of the task was achieved. At the end of each task, the respondent evaluated the interface on the following grounds: clarity of actions when working with the interface; the speed of work; the number of errors during operation; subjective satisfaction. The actions of the respondents were guided by estimation instructions. To process the data for each of the ten operations, the root mean square values for each of the four parameters and the root mean square values of each of the four estimates were found. That is, the root mean square value of the estimate denoted as empirical data was indicated by squares in the figures and plotted in red. To calculate and graphically represent the generalized interface estimate according to model (3), one examined attribute was considered as variable and the other three were recorded. Their values were determined as root mean square values of ten requests. Hereinafter, the index defined in this way was marked in blue in all figures and the curves in the figures were named analytical. Fig. 1 shows the dependence of the root mean square values of estimates of the intelligibility attribute for requests which was determined according to each of the strict sequences of the set of identical tasks.

As seen from the trend of curves for different operations-requests, this interface was characterized by respondents as one that is not equally clear when working with different tasks. However, despite the oscillatory nature between the empirical data obtained directly from respondents (Empirical Data curve) and the analytical ones, consistency could be traced. Calculation of the coefficient of determination for the whole set of estimates of respondents and requests was estimated at *R*=0.9742 which confirmed high reliability.

Fig. 2 presents data on the root mean square speed of the interface as a function of the same list of operationsrequests which was indicated for all respondents.

Despite different variabilities of the speed curves for different requests and different methods of plotting empirical and analytical curves, mainly better uniformity of changes was observed between these curves. The latter was also confirmed by a higher value of the coefficient of determination *R*=0.9819 which in turn means higher reliability of the model.

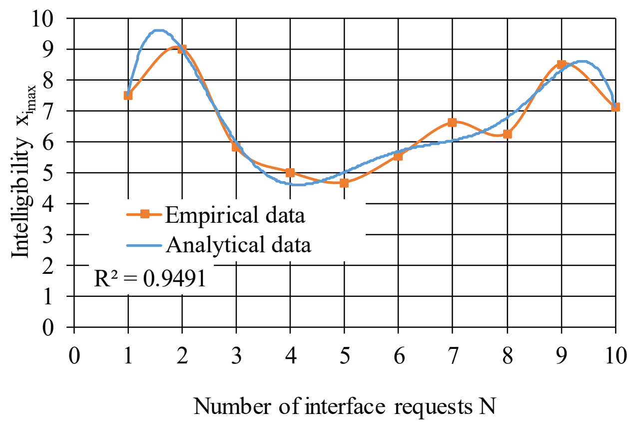

Fig. 1. Dependence of the intelligibility criterion of the user interface on the number of requests

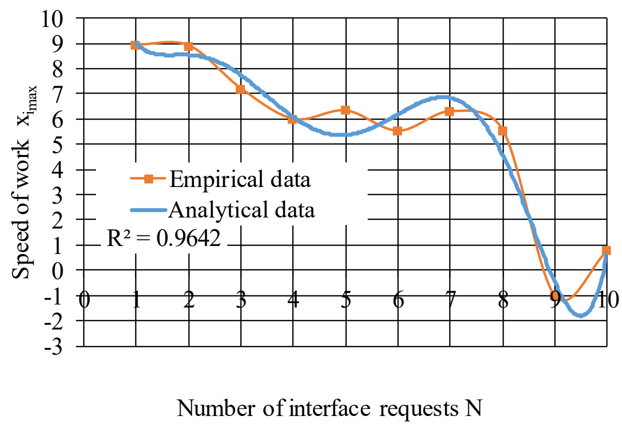

Fig. 2. Dependence of the criterion of the speed of work with the user interface on the number of requests

The curves of the dependence of the root mean square values of the estimates provided by the respondents and presented in Fig. 3 and those calculated from (3) for the attribute of the number of errors as a function of the request number were consistent as well.

However, the value of the coefficient of determination here was the smallest *R*=0.9567. The nature of change in the fourth index (subjective satisfaction) based on experimental data is presented in Fig. 4. The latter index for analytical data had less fluctuation than for empirical data and the coefficient of determination *R*=0.9754 confirmed high reliability of the obtained experimental data.

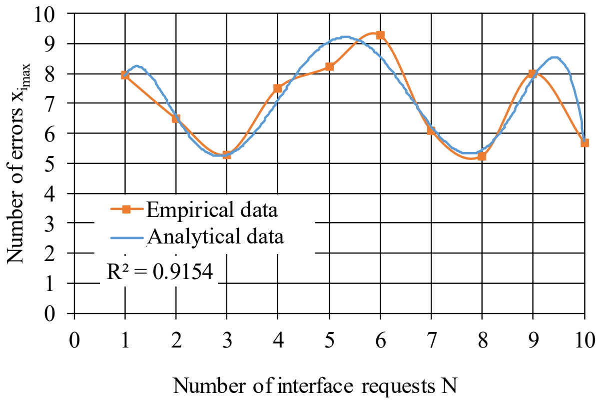

Fig. 3. Dependence of the criterion of the number of errors when working with the user interface on the number of requests

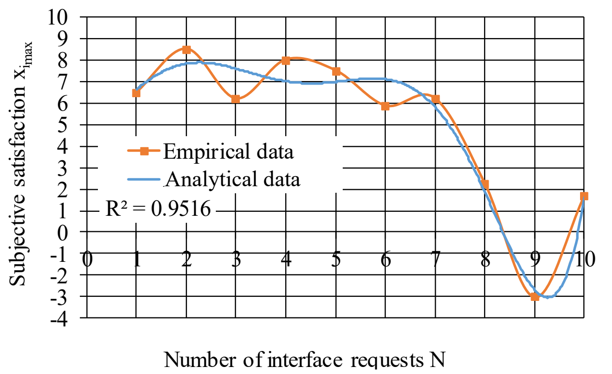

Fig. 4. Dependence of the criterion of subjective satisfaction when working with the user interface on the number of requests

The study results given in Fig. 1–4 can be presented in another form. Assume that like to these figures, there is a common axis of the number of requests to the interface for a set of four factors. Under these conditions, a general expression of the n-th index ranging from −10 to 10 to be mapped to the plane will be turned by angle $(\pi/2)n$ after multiplication by the factor $\exp(\pi ni/2)$. Analytical data will also be applied to this plane. Qualitative indicators are represented by the normalized membership function. The reliability of approximation of the data for each graph is characterized by the value of the coefficient of determination R^2 which shows the degree of compliance of the constructed model with the initial data. Its value is in the range from 0.9567 to 0.9819.

The complexity of the process of estimating the reliability of information consists in that information should be estimated as a whole in such a way that the probability of describing insignificant parameters does not appear to be a cover for the actual state of the object [24, 26]. Generalization of the modeling algorithms as well as making a forecast for nonlinear models of trends for time series and examples of numerical data are discussed in [27]. To estimate the reliability of the constructed information model of interface quality, the method of multifactor correlation-regression analysis will be used.

The degree of influence on the studied generalized index will be estimated by comparing the index of the generalized estimate and the index for which values of the three factors were fixed at an average level.

Thus, Fig. 1–4 and values of the coefficients of determination and dynamics of averaged values of indicators represent the reliability of the proposed method of generalized estimation of the software interface quality.

5. Discussion of the results obtained in the problem solution and the experiment on the generalized estimation of the index of software interface quality

The experimental results have demonstrated the workability of the method constructed as a tool of generalized estimation of the software interface quality by a set of three quantitative indicators and one qualitative index using a three-level comparator. The proposed set of two Euclidean norms $\|X_i\|$ according to (1) and $|QUI|_{max}$, due to their strictly consistent application, has allowed us to average values of indicators by attributes. This sequence normalizes them and at the same time leads to a single metric space with one interval of values. Thus, quantitative and qualitative estimates are presented in one metric space to which generalized estimate is also mapped. The axiomatic assumption about the influence of zero attributes on the generalized index and its continuity and properties of the geometric inequality have ensured the results obtained. It is this step of consecutive application of two norms proposed theoretically and implemented experimentally in this study that has allowed us to obtain an estimate of the quality of the software interface which was experimentally generalized (Fig. 1–4). Determination of the set of values of the integral index of interface quality using the method of recurrent approximation and the relative error properties makes it possible to conduct extensive experiments and create trends based on the attribute trends. Application of the three-level comparator makes it possible to use and represent negative estimates in the field of negative numbers which in the respondents' opinion is promising because it takes into account the user psychology and simplifies estimation. This conclusion with the use of quadratic Euclidean norm has reduced the problem of estimating the generalized index to the problem of determining the vector modulus by its components and rules of vector algebra which could not be realized in [24, 27]. Spatial representation of empirical trends of attributes with rotating coordinate planes is a means of visualization. To apply methods of multifactor correlation-regression analysis in estimation of the degree of influence on the studied resultant index, each of the factors introduced into the model is determined at the values of other factors fixed at the average level.

Thus, the proposed method of estimating the quality of software interface, QUI, has advantages over other methods considered in this paper as it allows one to combine analysis of quantitative and qualitative factors. However, the method considered the four-attribute QUI model. With an increase in the number of analysis factors, this method will not be able to assess the impact of each factor to a sufficient degree. Because of the dependence of the maximum possible error on the value of the integral index of QUI and the number of factors, interval of the maximum possible deviation obtained from expression (5) will increase which means that the reliability estimate itself will fall.

6. Conclusions

1. Consecutive application of two Euclidean norms makes it possible to estimate the trend of the generalized quality index according to the idea of using a three-level comparator and establish properties of the relative error for the resulting trend of quantitative and qualitative indicators. The upper and lower boundaries of the generalized index of the interface quality are simple in representation through an algebraic product of the set of estimates of attributes and their number.

2. Application of a unified metric in a form of the largest value from the module of a trend of the overall quality index according to the idea of spatial representation with rotating coordinate planes for quantitative and qualitative indicators gives a simple 3-dimensional picture. To improve imagination and display of the generalized index of interface quality while reviewing the dynamics of its components, the plane of their reflections is turned by an angle determined by the value of the exponential factor by means of multiplying by an exponential factor.

3. As was defined by a group of students involved in experimental tests of integral estimation of the quality of the user interface for the MedInfoService system designed for medical statistical reporting and covering automation of curative treatment processes in outpatient clinics and hospitals, it is simple and accessible. Using the methods of multifactor correlation-regression analysis, the influence of each of the estimates of the model component attributes with a coefficient of determination in a range from 0.9154 to 0.9642 was studied for the generalized index of interface quality. The average estimate of three attributes enabled a compact representation in the plane of trend mapping the generalized index of estimation of software interface quality.

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