DEVELOPMENT OF A METHOD OF PROVIDING ERGONOMICS OF A WEB-INTERFACE FOR CUSTOMERS OF A VIRTUAL INSTRUMENT-MAKING ENTERPRISE WITH LIMITED PHYSICAL CAPABILITIES

A method has been developed and implemented to ensure the ergonomics of using the Web interface for customers of a virtual instrument-making enterprise with limited capabilities through the use of expert systems. The essence of this method is to supplement the dialog component of the Information and Analytical Portal (IAP) with a specialized shell of the expert system (ES), which, being filled with knowledge about the limited capabilities of users caused by various pathologies, makes it possible to adapt the interface in the dialogue to the capabilities of a particular user. implementations of this solution method are fully consistent with the results obtained using the principles of interface improvement. However, due to the use in this synthesis method of various approaches to the technology of expert systems development, additional opportunities open up in solving the problem of providing the convenience of using the interface for customers with limited capabilities.

When using the proposed method, it becomes possible to simplify the procedure of interaction "man-machine", to solve the problems of people with disabilities, to increase the volume of consumers who have access to advanced information technologies. These facts, confirmed by the results of numerical modeling, showed the effectiveness of the presented method and an individual approach to users with disabilities. The software implementation of the logical-linguistic hierarchical model on the example of "strong myopia" with the help of the production shell ES is proposed and substantiated. As the initial data, information about hardware was used, the use of which, in appropriate cases, will make it possible to increase the ergonomics of the IAP for users with disabilities

Keywords: expert system, interface ergonomics, logical-linguistic model, object-oriented approach

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1. Introduction

Every day Internet technologies penetrate more and more into various spheres of human life, forcing humanity to actively master new technologies. And given the fact that more than a billion people worldwide (more than 15 % of the world's population) are users who, according to the latest WHO estimates, have some form of disability, it becomes necessary to adapt Web interfaces to the requirements and characteristics of people with various physical capabilities. Therefore, in today's world, it is unreasonable to assume that all users interact with digital products in the same way. Accessibility is becoming a critical element in process design that focuses on inclusion and diversity. That being said, digital products are usually designed only for the tangible majority of users – for those who have no difficulty using mobile or web applications. As a part of society, a person with disabilities has every right to both self-realization and

self-realization in society. One of the means of achieving realization in society is communication. The main communication tools for billions of people in our time are mobile communications and computers. Therefore, for effective interaction between a customer with disabilities and a PC, it is necessary to provide a "correctly" designed Web interface. After all, "unsuccessful" interfaces are a source of stress and psychological discomfort arising from the suboptimal distribution of functions in the "man-machine" relationship as a result of imposing inconvenient algorithms. Improving the efficiency and safety of the "man-machine" system requires a comprehensive consideration of the factors of interaction between the user and the machine. It is also necessary to take into account the properties of the resulting ergo-technical environment, in which the effects of the user's intellectual and social behavior and the intellectual components generated by the technical system are manifested.

Investigating the market for software and hardware for people with disabilities, it is possible to admit that the state of the segment is far from perfect. At the same time, judging by the organizations and developers, it is not difficult to create favorable conditions for customers with disabilities, because the level of development of information technologies today, to a certain extent, makes life easier for millions of users.

But virtual product developers rarely worry about their products being interacted with by people with a broken arm, poor eyesight or hearing. After all, an accessible product in a simple sense is one that allows each user to consume content. Therefore, in the era of global computerization and the attraction of more and more people to information technologies, computer technologies are increasingly woven into the living space of a person and play an important role regardless of its physical capabilities.

In modern economic conditions, there is a need for a product (services), which requires an innovative approach to its production. At the same time, enterprises can't always carry out such developments, given the specificity of the problems, the high level of costs for restructuring the production process or the complexity of the hierarchy of management and decision-making, and the like. Therefore, under the influence of the processes of globalization and international integration, with the development of the latest information technologies and increased competition, there is a need for cooperation between companies, creative teams and individuals, linked by a common goal and, most importantly, by key competencies that are necessary to solve the assigned tasks. All this creates a need for new forms of doing business, one of which is virtual instrument-making enterprises [1], which are gaining more and more development.

The first virtual enterprises appeared in the countries of Western Europe, the USA, since it was in these regions of the world that conditions were created for the predominant development of the new post-industrial economy [2].

The peculiarity of users of mass information systems is their lack of systematic education in the field of computer technologies and programming and the presence of specific experience not related to the practice of working with existing computer interfaces. The consequence of this is the lack or weak development of the mass user skills in working with interfaces of information and technical systems. At the same time, the number of tasks aimed at a general user is growing rapidly due to the general computerization and the trend of development of virtual production. Therefore, every year the

attention to the usability of information products is growing. An increasing number of software developers are thinking about how to make working with their products as accessible, comfortable and efficient as possible.

Today, virtual organizations act as temporary forms of cooperation between agents, giving rise to completely specific socio-economic relations, acquiring special significance when taking into account the needs of customers with disabilities and developing an improved software interface. Indeed, at present, the category "virtual reality" invades almost all spheres of society and gives rise to new phenomena. Virtual organizations are perhaps one of the brightest representatives of a new type of company based on knowledge, intelligence and innovation. The phenomenon of virtual organizations, having emerged more than ten years ago, is becoming more widespread in modern socio-economic systems. At the same time, one can observe a gradual transformation of virtual organizations from marginal to routine economic practice.

The modern present takes place in the era of the completion of the third, digital revolution, is marked by the development of information and communication technologies, automation and robotization of production processes, began in the second half of the last century, which will inevitably be replaced by the so-called Industry 4.0, which marks a new level of complete automation of production, where all processes are controlled in real time and taking into account changing external conditions. The essence of this priority area is to establish direct contacts between manufacturers and customers by improving the Web interface, taking into account their physical characteristics.

So, taking into account the special physical disabilities of customers, the virtual thus gives them equal opportunities in receiving high-quality consumer services at a level with customers that do not have such deviations. That is why virtual business, focused on the needs of customers with disabilities, is the catalyst that leads to the creation of new models of market relations, new associations of partners. And in the end – to a qualitatively new economy, capable of bringing any country to the level of highly developed countries, increasing its competitiveness.

2. Literature review and problem statement

In [1], dynamic partner networks are considered as the basis of virtual enterprises for the constant search and fulfillment of individual market orders and are intended to provide a quick selection of partners and organize them into a single system for a specific market order or project. Also, the authors have developed single-criteria and multi-criteria models for the distribution of standard orders, taking into account such order parameters as time, quality and cost of execution, with different resource constraints for different situations. For example, when one order can be completely fulfilled by one partner; to distribute a set of orders across a set of partners. An optimization model for the formation of a network of partners based on the methods of network planning and management, linear programming and multi-criteria choice is proposed.

The authors in the study [2] argue that the idea of a virtual corporation will become the center of a new business revolution. Their concept integrates various characteristics such as just-in-time delivery, flexible manufacturing, CAD and customization.

However, despite the obvious advantages of the development of virtual organizations, considered in works [1, 2], the question of ensuring the availability of their interaction for customers with disabilities remains open.

The work [3] includes the basics of modal and temporal logics, analysis of natural languages, Montague semantics, non-monotonicity of logics and logical theory of databases using the semantic and axiomatic approach. But at the current level of actual knowledge, the semantic and axiomatic approaches represent two different ways of using relational database extensions, but at present, for acceptable extensions, one of them can't be given an advantage in terms of the efficiency of the execution mechanisms that they need.

In work [4] it is noted that the most valuable thing in virtual organizations is that they are formed from personalities who bring in their own conceptual communication into the activities of organizations. The behavior of a virtual organization reproduces the spatio-temporal characteristics of the behavior of an object of a traditional organization. At the same time, if for some virtual objects and processes only a certain similarity of the logic of human activity with the logic of virtual reality is necessary, then for virtual organizations computerization and intellectualization of the main processes are the most significant attributes. The organization is "virtualized" to the extent that compliance with norms, turns the organization of production into an institution, becomes virtual.

The methods of development, design and creation of software and hardware, functioning on the basis of fuzzy situational algorithms for information processing, are discussed in [5]. In this work, two types of fuzzy models used in the construction of systems are considered, they advise: "situation - action" and "situation - control strategy - action". A classification of fuzzy operations is given, possible processor architectures for their implementation are analyzed. The architecture of a prototype of a computing complex for processing fuzzy information is described, and examples of the operation of a software instrumental complex for designing situational systems are given. The examples of building control systems for production processes based on the developed hardware and software are considered.

To implement the method of ensuring the ergonomics of using the Web-interface of a virtual instrument-making enterprise for customers with disabilities, the methods and algorithms developed in the study [5] have an obvious practical orientation. So, methods and algorithms for decision-making based on fuzzy inference schemes more fully than those already known, take into account the peculiarities of applied problems. In particular, they allow the use of both numerical and linguistic values when describing input and calculating output situations of decision making. Methods and algorithms for determining fuzzy invariants of fuzzy graphs make it possible to formulate and solve combinatorial problems of a wide class. Indeed, it is often almost impossible to obtain accurate information when analyzing the functioning of a complex or multidimensional system, and if possible, in most cases it turns out to be of little use and such that it is difficult to interpret. A simplified model provides time-based information that is more understandable than a detailed and more accurate model. In addition, the use of classical methods for choosing solutions in complex systems is significantly limited by the difficulties of forming a single criterion, covers different, and in some cases, contradicting requirements. So, for example, when solving many practical problems, it becomes necessary to optimize the speed of the system and minimize its energy costs or ensure maximum accuracy, etc. Finally, the most important problem of choosing solutions is associated with the formalization of uncertainties, the numerous sources of which are of different nature. First of all, they should include the errors of calculations and measurements, which lead to the possibility of establishing the parameters of the current state of the object and its external environment only with a certain probability. On the other hand, the conditions for the autonomous functioning of a number of special-purpose systems are characterized by the a priori incompleteness of the working environment, the unpredictability of its changes, the randomness of external disturbing influences and the fuzziness of formulated goals.

In work [6], the rules of conditional inference, work with linguistic variables are fully investigated, the implementation of the EC in the "ExpertSys" shell is carried out.

In work [7], the methodological foundations of constructing expert systems are considered, and their classification is given. Very clearly, using examples of real systems, an idea is given of various approaches to building knowledge bases. The current strategies for finding solutions and methods for reducing the search space are described.

The method of increasing the efficiency of information systems using 3D visualization is investigated by the authors in [8], based on visual information, which allows to significantly increase the bandwidth of the information channel through which the two-way communication between the user and the computer is carried out, and therefore the role and significance of the figurative presentation of the results computing in industry and research practice is growing steadily. And image synthesis systems act as a tool that ensures the creation and functioning of hybrid intelligence systems that combine human creativity with the information, computational and visual capabilities of a PC. The authors also consider spatial 3D visualization as the beginning of a new direction in the technology of creating human-machine interaction systems. However, the requirements for realistic images are constantly growing, which, in the end, implies an increase in computational costs. Also, volumetric visualization requires a significant complication of the computational process due to laborious procedures of 3D model generation and three-dimensional spatial processing, which significantly limits the speed of formation of volumetric images of graphic scenes and, in turn, makes it almost impossible to implement dynamic modes of image generation in real time. So, today there is a contradiction between the capabilities of modern systems for the formation of three-dimensional volumetric graphic images with the needs of many applications, for which it is necessary to further develop the theoretical foundations of image synthesis in order to increase their productivity and realism.

The widespread use of computers has led to the solution of important problems related to the analysis of accumulated information in order to bring knowledge to a new level, and a need arose for the creation of data warehouses and system support for decision-making based, among other things, on the methods of the theory of artificial intelligence, are considered by the authors in [9]. The authors highlight the main directions in the field of data analysis: data storage organization, online (OLAP) and intelligent (Data Mining) data analysis. It also introduces a description of methods and algorithms for solving the main problems of analysis: classification, clustering, etc. But this study does not allow

determining among the proposed tools and algorithms the most effective for data analysis.

In [10], the practical development of artificial intelligence technologies and expert systems is considered. This makes it easy and concise to present fairly complex concepts and methods with minimal prior knowledge of the reader in this area. However, despite the fact that the study of the main components of artificial intelligence and the ES is illustrated with examples of programming the corresponding methods and tasks, the results presented in [10] are of a more conceptual nature.

In [11], the fundamentals of multidimensional data analysis and deep data representation of multi-day data and OLAP server devices are considered. The basic concepts of the MDX multidimensional data access language and its extended capabilities, as well as the server architecture, data processing and data access algorithms are described. Internal and external communication protocols, including the XML/A protocol, are implemented. Algorithms for managing Analysis Services resources, including memory management algorithms, are considered. The described process of creating effective client programs using analysis services, mechanisms for integrating multidimensional and relational databases. Focus on security and administration of Microsoft SOL Server 2005 Analysis Services.

In work [12], the basic concepts of expert systems technology are considered. But the main schemes for representing problem-oriented knowledge in programs and methods of applying this knowledge to solving complex problems using a computer are not well covered.

In [13], a description of the shell of expert systems is given; according to the authors, it needs to be revised and improved.

The life cycle analysis method [14] is a widely used tool for substantiating strategic choices aimed at the regular appearance of new products and the development of promising businesses. The advantage of the proposed approach is the work [14] is that it easily lends itself toalgorithmization, and this is another aspect that can't be ignored at the present stage of development of marketing technology. The latest achievements in automation based on OLAP technologies with a data mart for information support can significantly facilitate solving problems using the tool in question and signal in real time about the status of individual positions or entire groups in the company's product portfolio.

Reference [15] shows the ergonomic requirements for office work using video terminals (VT). Part 11: Guidance for determining and measuring suitability.

Source [16] "World Report on Disability" compiles all available information on disability in order to improve the lives of persons with disabilities and to promote the implementation of the "Convention on the Rights of Persons with Disabilities".

The sources [17, 18] describe the requirements for creating an Internet resource for people with disabilities. But these requirements are not a holistic and ready-made methodology for creating an Internet resource for visually impaired people, since they do not contain a consistent, hierarchical structure of the importance of existing conditions. At the moment, there are only standards in this area and their variations are common.

There is also research [19] that gives an idea of the devices and specialized software used by people with disabilities. But it does not resolve the issue with the priority of the implementation of certain recommendations (criteria). Thus, the question of determining the importance of this or that criterion remains open.

The method of analyzing hierarchies [20] seems to be more justified by solving multi-criteria problems in a complex environment with hierarchical structures, including both tangible and intangible factors, than the approach based on linear logic. Applying deductive logic, researchers go through the difficult path of constructing carefully meaningful logical circuits only in order to, as a result, rely on intuition alone, to combine the various conclusions drawn from these deductive premises. In addition, an approach based on logical chains may not lead to a better solution, since in this case the opportunity to make trade-offs between factors lying in different chains of logical thinking may be lost.

The results of the above studies reveal the need to develop a procedure for the synthesis of control of technological processes with a corresponding finding of optimal criteria in the development of a method for ensuring the ergonomics of using a Web interface for customers of virtual instrument-making enterprises with limited capabilities.

3. The aim and objectives of research

The aim of research is to develop a method for ensuring the ergonomics of the Web interface for customers of a virtual instrument-making enterprise with limited physical capabilities. That will make it possible to improve the economic performance of the enterprise by expanding the client base of customers by providing customers with a virtual instrument-making enterprise with different life indicators, equal opportunities in obtaining high-quality consumer services.

To achieve the aim, the following objectives are set:
– to analyze the usability method and ES development tools;
– to carry out mathematical modeling of the ES interface ergonomics.

4. Materials and methods of research

The developed method is based on the basic technology for the development of expert systems [6, 7]:
1. Acquisition of knowledge about physical limitations that reduce the IAP usability.
1. 1. Classification of physical limitations that reduce the usability or exclude the use of the standard IAP interface by users with disabilities.
1. 2. Allocation of subclasses of physical limitations.
1. 3. Determination of the degree of physical restrictions within each allocated subclass.
1. 4. Formation of sets of software and tools, the use of which is justified in accordance with the degree of one or another physical limitation.
2. Representation of knowledge acquired at the previous stage in the knowledge base (KB).
2. 1. Formation of antecedents of production rules as sets of symptoms.
2. 2. Formation of consequent production rules in the form of recommendations for the use of special software and hardware.
3. Development of a subsystem of explanations.

The analysis of the shortcomings of the customers of the virtual instrument-making enterprise was carried out using the clustering of statistical data and processed using the StatLab systems.

The dialog component of the information and analytical portal (IAP) was supplemented with a specialized shell of the expert system in accordance with the ISO 9241-11:1998 standard, which is the key to ensuring the suitability of the updated Web interface for customers with disabilities, as such, it will fully satisfy the needs of the user by providing the ability to solve emerging problems with the required efficiency and effectiveness.

The processing of knowledge in the expert system (ES) of the ergonomics of the PC user interface was carried out using an object-oriented approach, which made it possible to effectively simulate the human thinking process.

A sample of the method of ensuring the ergonomics of the Web-interface for customers of a virtual instrument-making enterprise with limited physical capabilities is shown on the basis of a virtual instrument-making enterprise Scientific and Production Enterprise "KIATON" (Kharkiv, Ukraine).

5. Results of the analysis of the usability of methods and tools for developing ES

A formal definition of a metasemantic network is introduced to establish relationships and the nature of the classification of the objects under study.

Relationships are a way of organizing a specific set of objects. Usually identified with the concept of a predicate. In this case, relations are understood as a symbolic designation of the real interaction of one or more objects. Let's distinguish between directed and non-directed relationships.

"Relationships are not directed" – relationships indicate some property of one or a group of objects.

The second class of relations (directed) exists between one or a set of initial objects (subjects of interaction) and one or many initial objects (objects of interaction). For example, in the expression "{1, 2, 3, 4} is N", the group of objects 1, 2, 3, 4 is the subject of interaction, the set N (natural numbers) is the object of interaction and the relationship "is" (belonging) is the relation …

Let's determine how n-ary non-directed relations can be reduced to unary relations, and n-ary directed ones - to binary relations.

Forms of representation of relations:

1) predicate: a semantic predicate is introduced:

$P(A_i, L_k, A_i)=1$, if there is a relation L_k between the objects A_i and A_j;

0 otherwise.

The predicate is a form of representation of binary or unary relations $P(A_i, L_k, A_i)$ for the case of n-ary directed and directed relations, let's introduce a predicate of the following form:

As

$$P\left(A_1^S, A_2^S,..., A_m^S, L, A_1^0, A_2^0,..., A_K^0\right)=1$$

if there is a relation L between the set of objects As and A_0;

0, otherwise;

or in shorthand:

$$P(A_s, L, A_0),$$

where A_s– set of subjects of interaction; A_0 – set of objects of interaction; L – n-ary ratio; the sets A_s and A_0 are non-empty, disjoint, or completely coincide; if the sets A_s and A_0 coincide, then the predicate denotes an n-ary undirected relation;

2) graph: graphical representations serve to globalize and structure information. The graph gathers all information on some object around one node. Graphical representations, such as conceptual graphs and semantic networks, allow to visualize the model of the world to which the problem being solved belongs. This type of representation reflects objects of the subject area more than rules related to this world itself.

A compassionate way to classify objects is established:

1) atomic objects – objects whose structure is currently unknown; such objects are represented by the top of the semantic graph;

2) complex objects – objects that have composition and structure; complex objects associated with their constituent parts by the relationship "mother part" (HAS_PART) in classical SS complex objects are depicted as shown in Fig. 1, *a*; in this work, parts of an object are depicted inside its envelope (Fig. 1, *b*). This classification method is associated with the relationship "this" or "have a part" (HAS_PART) means that elements of a lower level in the network can inherit the properties of elements of a higher level in the network.

Another classification method is related to the class member relationship (IS_A). From this point of view, let's distinguish:

1) physical objects – a reflection of real physical objects or phenomena (often such objects are called instances);

2) metaphysical objects – classes, types, types of objects and relationships.
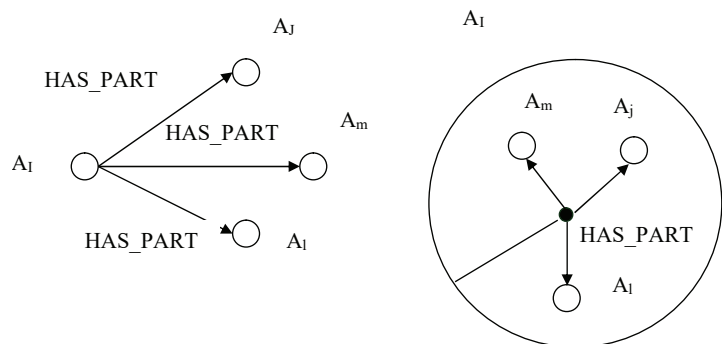

Fig. 1. Images of classical semantic networks of complex objects: *a* — parts of a complex object without a shell; *b* — parts of a complex object inside its shell

Physical objects can be related to metaphysical class objects by the "class member" relationship. Thus, a number of physical objects can be linked into one class.

Metaphysical objects – classes directly related to physical objects, let's call meta-objects of the first level. Meta-objects of the first level can also be declassified and associated with the meta-objects of the next level by the relation "class element", etc.

Each relation between objects can be put in accordance with a meta-object – a reflection of the relation, which let's call the semantic carrier of the relation and denote by the symbol AL_i. Fig. 2 shows an example of the image of a semantic medium on a semantic graph.
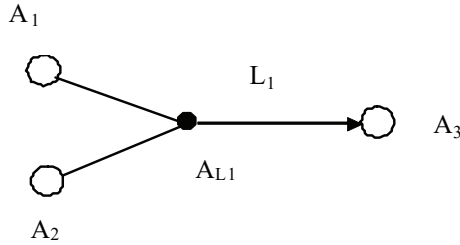

Fig. 2. Representation of a semantic carrier on a semantic graph

Between the semantic carriers of relations, there can be relations that can be called meta-relations. Any meta-relationship can be associated with its semantic carrier, between which there can also be the goal of a higher-order relationship. For the goal of the relationship, let's introduce the following notation: where n is the order of the goal of the relationship. In the general case, let's assume that the relationship between physical and metaphysical objects is a zero-order relationship.

An example of first-order meta-relations can be products of the form:

$$R_i : \text{IF}\left(S_i\right)\text{THEN } P\left(A_j^s, L_j, A_j^0\right), \qquad (1)$$

where S_i – some conjunction of predicates.

If each relation L_i and relative to L_j is assigned a semantic carrier AL_i and AL_j in a form-like manner, then the production R_i can be considered as a meta-relation LR connecting objects AL_i from object AL_j. Similarly to meta-production of order n:

$$R_i^n : \text{IF}\left(S_i^j\right)\text{THEN } P\left(A_{L_j^{n-1}}^s, L_{R_j^{n-1}}, A_{L_j^{n-1}}^0\right), \qquad (2)$$

where S_i^n – some conjunction of predicates; $P\left(A_{L_i^{n-1}}^s, L_{R_i^{n-1}}, A_{L_i^{n-1}}^0\right)$ can be considered as an n-th order meta-relation.

Let's introduce the concept of the state of a metasemantic network (MS). By the MS state let's mean a record of the form:

$$S = \langle A_i^S, A_j^O, L_k \rangle, \qquad (3)$$

where A_i^S, A_j^0 – sets of objects (including sets of material carriers of relations); L_k – relations between them (including meta-relations).

Let's introduce a restriction: relations between the carriers of relations, as well as between material carriers of relations of different levels, are prohibited.

When graphically depicting the MS level, each of the conjunctivas from formula (3) is associated with the image of the ratio. For example, statements

$$P(A_1, A_2, A_3, L_i, A_4, A_5)^\wedge$$
$$^\wedge P(A_6, L_2, A_2, A_3)^\wedge P(A_5, L_3, A_6)^\wedge$$
$$^\wedge P(AL_1, AL_2, L_l, AL_3) = 1 \qquad (4)$$

corresponds to MS, shown in Fig. 3.

Thus, by MS let's mean a triple <A, L, S>, where A – set of MS objects (physical, metaphysical objects, material carriers of relations of all levels), L – set of relations and meta-relations, S – current MS state.
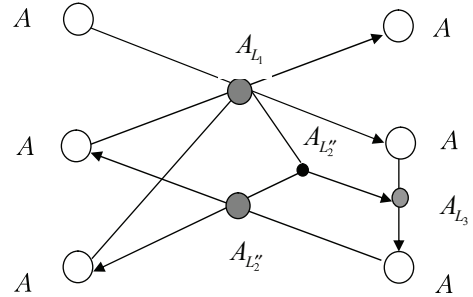

Fig. 3. Graph corresponding to expression (3)

The specified interface is focused on the organization of friendly communication with the user, both in solving problems and in the process of acquiring knowledge and explaining the results of work [3].

Consultation on the ES can be conditionally divided into two stages [10]:

1) the user's answers to questions;

2) recommendation of the system, based on the analysis of the entered data.

To store intermediate data, a database (DB) is included in the structure of the ES ergonomics of the PC interface (Fig. 4), for the effective operation of which a control subsystem is provided.

The developed decision support system (DSS) also supports the following functions:

1) ensuring the modification of the knowledge base;

2) ensuring the conclusion of explanations for the ES's decision;

3) possibility of rollback, that is, returning back to the desired place of consultation for clarification or correction;

4) providing protection against unauthorized access;

5) presence of a convenient and easy-to-use interface.

To ensure reliable operation of the system,

1) centralized storage of data, allows to ensure their integrity;

2) control of the correctness of entering the necessary information;

3) ensuring the protection of data from unauthorized access;

4) restoring the system after a failure or after incorrect completion of information on the data and displaying a notification to the user.

Inference is the central concept of knowledge-oriented systems. It has two aspects: using considerations to find different assumptions that are determined by the facts and rules, or to study conclusions that may or may not be true. The study of the rules of conditional inference covers three types of conditional sentences [5]:

R1: IF $X \in A$, THEN $Y \in B$;

R2: IF $X \in A$, THEN $Y \in B$ and C;

R3: IF $X_1 \in A$, and $X_2 \in A_2$ and ... $X_n \in A_n$, THEN $Y \in B$.

ES database of PC user interface ergonomics			

Types of physical disabilities
Mild myopia
Moderate myopia
Severe myopia
Mild hyperopia
Moderate hyperopia
Severe hyperopia
Open-angle glaucoma
Closed-angle glaucoma
Concomitant squint
Paralytic strabismus
Dysbinocular amblyopia
Hysterical amblyopia
Obscuration amblyopia
Hearing loss I degree
Hearing loss II degree
Hearing loss III degree
Hearing loss IV degree
Deafness
Violation of the spoken side of speech
Systemic speech disorders
Dysgraphia (violation of writing)
Dyslexia (reading disorder)
Dislocation
Fractures
Rachiocampsis
Dystrophy
Paralysis
Joint diseases
Lack of limbs

Intensity of physical disabilities			
Visual impairment	Weak	Average	Critical
	Mild myopia	Moderate myopia	Severe myopia
	Mild hyperopia	Moderate hyperopia	Severe hyperopia
Hearing impairment	Hearing loss I degree	Hearing loss II degree Hearing loss III degree	Hearing loss IV degree Deafness

Fig. 4. ES database of PC user interface ergonomics

The conceptual basis for formalizing the rules of conditional inference is the modusponens:

IF ($\alpha \rightarrow \beta$) is true I α true, THEN β is true,   (5)

there are rules that work when facts are found that satisfy its left side: if the premise is true, then the conclusion must also be true.

In turn, compositional rules are the methodological basis for such formalization. Fuzzy statement of a logical inference problem consists in determining a fuzzy set of consequences [5]:

PREMISE 1: IF X∈A, THEN Y∈B,

PREMISE 2: X∈A',

CONSEQUENCE: Y∈B',

where A and A'are fuzzy sets in the universe U; B – fuzzy set in the universe V, whence B' is a consequence presented as a fuzzy set in V.

To obtain a logical consequence, it is necessary to reduce prerequisites 1 and 2 to binary fuzzy relations of the form $R(A1(x), A2(y))$ and unary fuzzy relations of the form

$R(A1(x)$, respectively. Here $A1(x)$ and $A2(y)$ are determined by the variables x and y, which take values from the universes U and V, respectively. Then $R(A1(x))=A'$, a $R(A1(x), A2(y))$ are determined by one of the rules [11]:

a) maxmin$(Rm(A1(x), A2(y)))$, as a result of which let's obtain

$$(A \times B) \cup (\text{not}(A) \times V),$$

where $\times$ – Cartesian product; $\cup$ – union; not – inversion.

b) arithmetic $(R0(A1(x), A2(y)))$, the result of which is

$$(\text{not}(A) \times V) \circ (U \times B),$$

where $\circ$ –maximum amount;

c) mini-functional $(RC(A1(x), A2(y)))$, as a result let's obtain.

So, the logical consequence $R(A2(y))$, equivalent to B', can be obtained as follows:

$$R(A2(y))=R(A1(x)) \circ R(A1(x) \bullet A2(y)), \tag{6}$$

where R – composition operation based on the main types of compositions of fuzzy relations.

Let's consider a straight chain of reasoning that suggests the use of rules to deduce (logical inference) new facts, as well as facts that have existed before, but can be made explicit through the application of rules: modusponens. The inference engine cycles through all the rules in the knowledge base (Fig. 5).

It examines each of them in turn, finding out if the information in the consequent of the rule is true. If it is true, the inference engine adds the fact on the right side of the rule to the stored true facts. It then moves on to the next rule and repeats the process. Thus, all the rules are checked.

The essence of the direct chain of reasoning is the invention of questions that allow at each step to discard a large number of possible answers, so that the correct answer can be established quickly enough. If at each step half of the possible answers are discarded, then direct inference is not inferior in efficiency to binary search.

Let's consider the essence of the direct chain of reasoning method using an example.
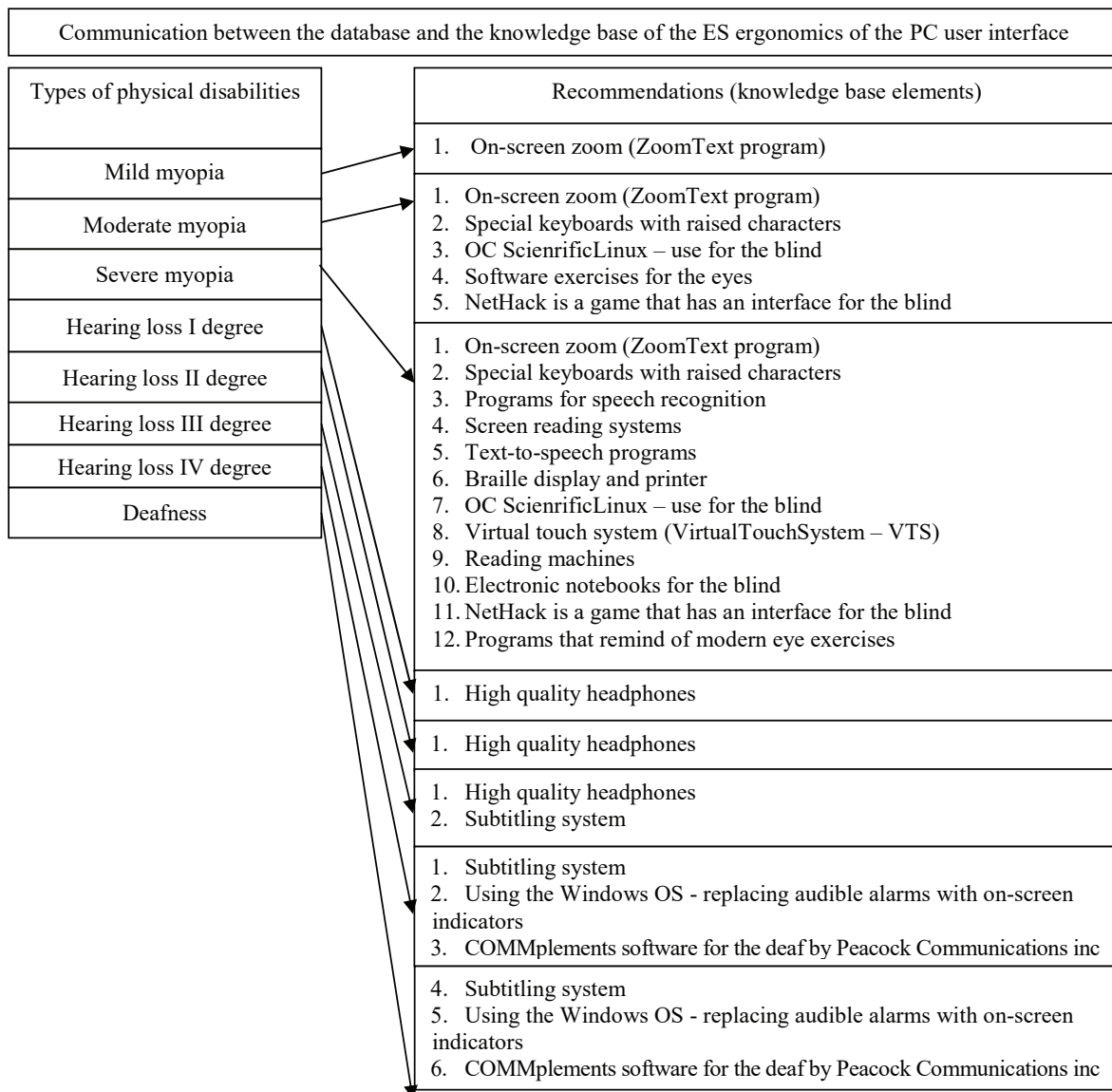
Communication between the database and the knowledge base of the ES ergonomics of the PC user interface

Types of physical disabilities	Recommendations (knowledge base elements)
Mild myopia	1. On-screen zoom (ZoomText program)
Moderate myopia	1. On-screen zoom (ZoomText program) 2. Special keyboards with raised characters 3. OC ScienrificLinux – use for the blind 4. Software exercises for the eyes 5. NetHack is a game that has an interface for the blind
Severe myopia	1. On-screen zoom (ZoomText program) 2. Special keyboards with raised characters 3. Programs for speech recognition 4. Screen reading systems 5. Text-to-speech programs 6. Braille display and printer 7. OC ScienrificLinux – use for the blind 8. Virtual touch system (VirtualTouchSystem – VTS) 9. Reading machines 10. Electronic notebooks for the blind 11. NetHack is a game that has an interface for the blind 12. Programs that remind of modern eye exercises
Hearing loss I degree	1. High quality headphones
Hearing loss II degree	1. High quality headphones
Hearing loss III degree	1. High quality headphones 2. Subtitling system
Hearing loss IV degree	1. Subtitling system 2. Using the Windows OS - replacing audible alarms with on-screen indicators 3. COMMplements software for the deaf by Peacock Communications inc
Deafness	4. Subtitling system 5. Using the Windows OS - replacing audible alarms with on-screen indicators 6. COMMplements software for the deaf by Peacock Communications inc

Fig. 5. Knowledge base of ES ergonomics of the PC user interface

Premise 1: if "moderate myopia" and "hearing loss IV degree" then "For people with such physical disabilities, let's recommend using:

1. On-screen magnification (ZoomText program).
2. Special keyboards with raised characters.
3. OC ScientificLinux – use for the blind.
4. NetHack is a game with an interface for the blind.
5. Software exercises for the eyes.
6. The system of forming subtitles.
7. Using Windows OS feature – replacing audible alarms with on-screen indicators.
8. Software for the deaf COMMplements from Peacock Communications Inc. ".

6. Mathematical model of ES interface ergonomics

As a mathematical model for describing the ES of the ergonomics of the PC user interface, let's choose a logical-linguistic production model.

A logical-linguistic production model is a mathematical object that is defined by the following axioms [11]:

a) the following sets are proposed:

1) a set of input influences $U = \{u_1, u_2, ..., u_M\}$, are linguistic variables characterized by $(u_j, S(u_j), V_j)$ $j = 1, ..., M$ sets;

2) a set of initial values $Y = \{y_1, y_2, ..., y_M\}$ are also linguistic variables characterized by $(u_k, S(u_k), V_k)$ sets;

b) the mapping of the output $R: (\omega) \to x(t)$, is given, which determines the state $x(t) \in X$, reaching the moment of time $t \in T$ for a fixed input action $\omega \in \Omega$ if at the initial moment of time $\tau \in T$ the initial state $x = x(\tau)$, $\tau \in T$ is in the form of sets of rules $R = \{R_1, R_2, ..., R_N\}$ such that

$$R: \text{IF } u_1 \text{ AND } u_2 ... \text{ AND } u_M, \text{ THEN } y_M = B_1, ..., B_M, \quad (7)$$

where

$$u_1 \in S_{1,j}^u = \{S_{1,1}^u, S_{1,2}^u, ..., S_{1,M}^u\},$$

$$u_2 \in S_{2,j}^u = \{S_{2,1}^u, S_{2,2}^u, ..., S_{2,M}^u\},$$

$$u_M \in S_{M,j}^u = \{S_{M,1}^u, S_{M,2}^u, ..., S_{M,M}^u\}.$$

For example, the rules take the form:

R_1: IF $T_1 = PS$ AND $V_1 = PB$ THEN $IO_1 = PS$,

R_2: IF $T_2 = PS$ AND $V_2 = PB$ THEN $IO_2 = PB$,

R_3: IF $T_3 = PS$ AND $V_3 = PB$ THEN $IO_3 = ZE$,

R_M: IF $T_M = ZE$ AND $V_M = PB$ THEN $IO_M = NB$, (8)

where NB – negativebig (very bad) NS – negativesmall (not very bad) ZE – zero (neutral Elements) PS – positivesmall (not very good) PB – positivebig (very good) and are fuzzy sets with given membership functions.

The number of set rules is in the range

$$0 \le K_j \le \prod_{i=1}^{N} \text{card}(S(u_i)), \quad (9)$$

where $\text{card}(S(u_i))$ – cardinality of the term-set of linguistic variables.

When analyzing the possible operating conditions of the electronic ES ergonomics of the PC user interface, it is necessary to take into account the hierarchical relationships between the input variables of the system. To solve this problem, a logical-linguistic hierarchical production model has been developed.

Proceeding from the fact that any hierarchically organized structure is based on the classification criteria for constructing the basis of a hierarchy tree to reflect the relationship of partially ordered sets, the hierarchy of management goals $L = \{L_0, L_1, ..., L_M\}$ was used as the skeleton of the tree. Each subset of the system defines its own level of the hierarchy. Hence, let's derive the definition of a logical-linguistic hierarchical production model.

The logical-linguistic hierarchical production model is called the logical-linguistic production model, which can be represented as [13]:

$$\bigcup_{j=1}^{M} \text{conseq} R_{i-1,j}^k = \text{antec} R_j^k,$$

where

$$R_1 : \bigcup_{j=1}^{M_{N_0}} L_{0,j} \to L_1, L_0 = \{l_1^0, l_2^0, ..., l_{k_0}^0\},$$

$$R_2 : \bigcup_{j=1}^{M_{N_1}} L_{1,j} \to L_2, L_1 = \{l_1^1, l_2^1, ..., l_{k_0}^1\},$$

$$R_M : \bigcup_{j=1}^{M_{N_{M-1}}} L_{M-1,j} \to L_M, L_M = \{l_1^M, l_2^M, ..., l_{k_0}^M\}$$

– linguistic variables.

The work of the ES ergonomics of the PC user interface is ensured through the use of linguistic rule tables (LRT). The knowledge base of the object is described with the LRT help. The nodes of the tree of the hierarchical system are LRTs, and the arcs are the goal of the rule, on the basis of which the desired LTR is selected in case of a change in the current ES goal. The movement along the tree of goals defines the ES, which models the central decision-making strategy.

Thus, the model of the ES presentation of the ergonomics of the PC user interface has been determined and substantiated – a logical-linguistic hierarchical production model, as the most appropriate for describing this system (Fig. 6).

As a result of the application of the described method in the IAP development, both an obvious social effect and an economic effect are achieved, since an increase in the number of IAP users directly affects the growth in the number of consumers of WFP products.

To create a software product, it is necessary to classify physical limitations in humans. The technical part of the software-algorithmic implementation of the logical-linguistic hierarchical production model has an objective-legislative nature [4, 6]. First, a certain number of rules were entered into the system. The rules are focused on the implementation of decisions to issue recommendations in the context of various combinations of scenarios:

Fragment of the software product for the implementation of ES ergonomics of the PC user interface:

```
«goal:Recomendaciya
initial:
rule:r1
if:a=1
then: Recomendaciya:=»For people with such disabil-
ities, let's recommend using 1. Screen Zoom (ZoomText
program)»;
rule:r2
IF:b=1
THEN:Recomendaciya:=»For people with such physical
disabilities, let's recommend using 1. Screen zoom (Zoom-
Text program) 2. Special keyboards with raised characters.
3. ScientificLinux OS - use for the blind 5. NetHack - game,
has an interface for the blind 4. Exercise software for the
eyes»;
rule:r3
IF:c=1
THEN:Recomendaciya:=»For
people with such disabilities, let's
recommend using 1. Screen mag-
nification (ZoomText program).
2. Special keyboards with raised
characters. 3. Speech recognition
software. 4. Screen reading sys-
tems. 5. Speech synthesis soft-
ware. 6. Braille display and print-
er. 7. ScientificLinux OS – use for
the blind. 8. Virtual touch sys-
tem (VTS). 9. Reading machines.
10. Electronic notebooks for the
blind. 11. NetHack-game with an
interface for the blind. 12. Pro-
grams that remind of timely exer-
cises for the eyes».
```

Technically, the program provides for the structural introduction of rules, on the basis of which the necessary scenario is subsequently selected (to generate the necessary recommendations) [1]. After entering data on the physical limitations of a person, the system, depending on the comparison of combinations, gives recommendations on the use of a certain set of hardware and software that can compensate for the physical limitations specified in the form of input data. The context of the rules is generated by inputting data during a computer-human dialogue. Further, the recommendations are reflected on the PC screen. A person also has the right to make a decision on these recommendations with the help of a separately installed shell for the development of ES [14].

One of the examples of this method implementation is the use of the ExpertSys system shell [13–15].

The advantage of the proposed method is that it is easily amenable to algorithmization, and this is another aspect that can't be ignored at the present stage of development of marketing technology. The latest advances in automation based on OLAP technologies with a data mart for information support for customers with disabilities can significantly facilitate the solution of problems using the tool in question and signal in real time about the status of individual items or entire groups in the company's product portfolio [14].

The shell of the proposed system "ExpertSys" was developed in accordance with the ISO 9241-11:1998 standard, which is the key to ensuring the suitability of the updated Web-interface for customers with disabilities, as such, it will fully satisfy the needs of the user, providing with the opportunity to solve emerging tasks with the required efficiency and efficiency [15].

Let's consider the implementation of this method of ensuring the ergonomics of the interface on the example of the operation of the virtual instrument-making enterprise SPE "KIATON", which uses the algorithm for selecting a marking device in screen forms on the information and analytical portal www.AGROPROM.in.ua, which is shown in Fig. 7.
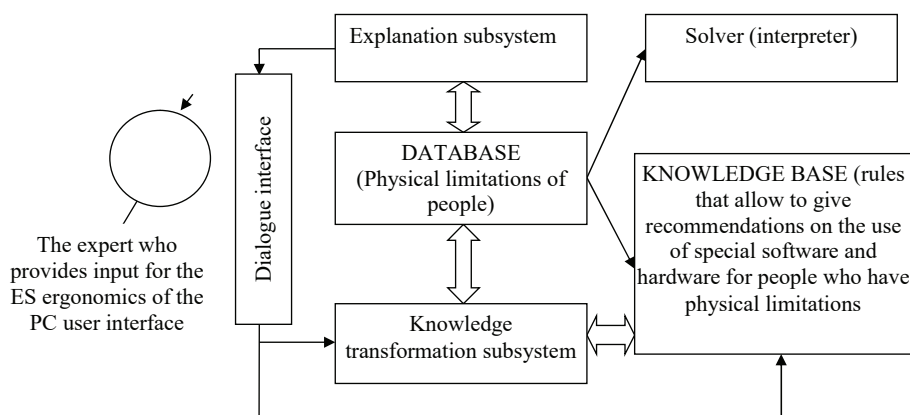

Fig. 6. Diagram of the expert system for the ergonomics of the PC user interface
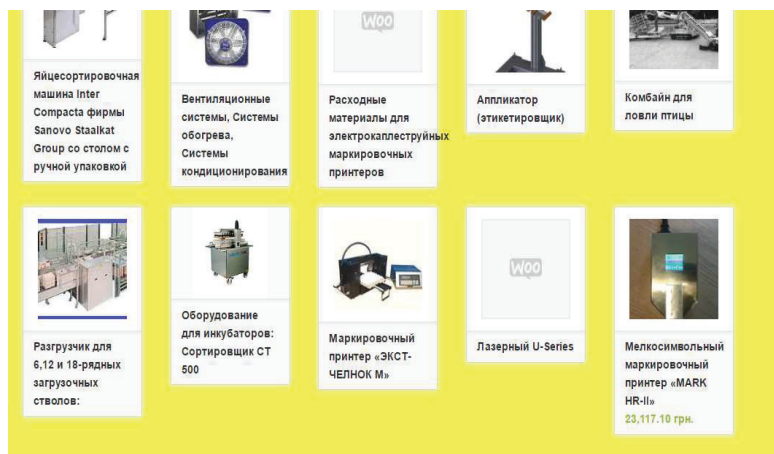

Fig. 7. Page for choosing a product from a category on www.AGROPROM.in.ua

After choosing the necessary product, the user of www.AGROPROM.in.ua can purchase it as follows (Fig. 8).

After choosing a product, the portal moves the user to the pre-registration page, where it is necessary to specify contact information (Fig. 9).

After registering on the portal, it is necessary to select the quantity of the product, and the selected product is automatically moved to the buyer's basket. The shopping cart reflects the number of products selected by the user, as well as the full

description of the product, its price and characteristics. After the generated order, the front view of the order appears, and the conditions for the delivery of the goods are set.
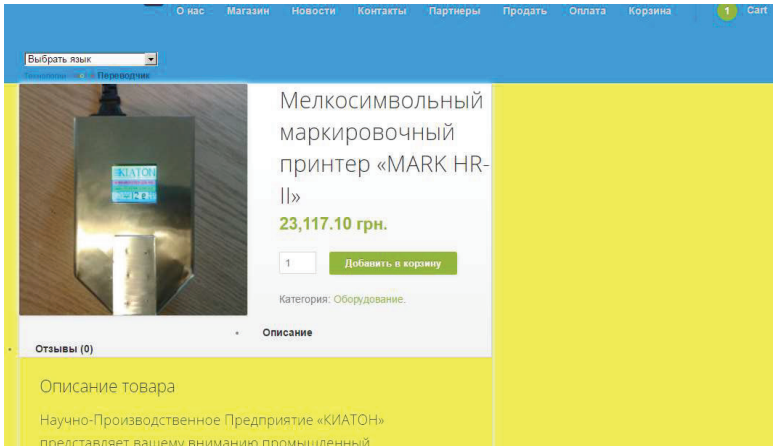

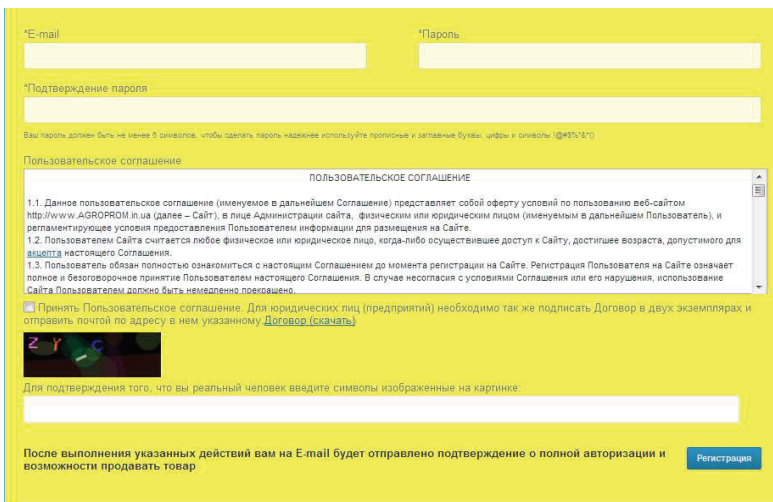Fig. 8. Display of product selection
by user www.AGROPROM.in.ua

Fig. 9. Pre-registration line for purchasing goods
on the portal www.AGROPROM.in.ua

When implementing the method of usability of the interface on the portal www.AGROPROM.in.ua., physical limitations in people are classified (Table 1).

Fig. 10 shows a screen form for selecting a recommendation scenario. The user needs to choose a specific answer.

Since the scenario "strong myopia" is being considered, using the drop-down list at the bottom of the window, it is necessary to select "Option No. 1" (Fig. 11).

After entering data on the physical limitations of a person, the system, depending on the comparison of combinations, gives recommendations on the use of a certain set of hardware and software that can compensate for the physical limitations specified in the form of input data.

Fig. 12 gives the recommendation of a set of software and hardware tools to compensate for the physical limitations introduced above.
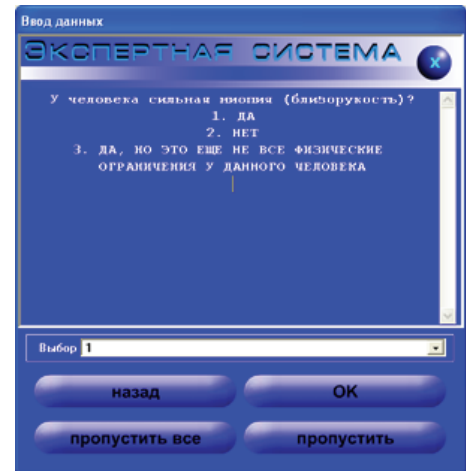

Fig. 10. Screen ES form of PC user interface
ergonomics for selection of scenario
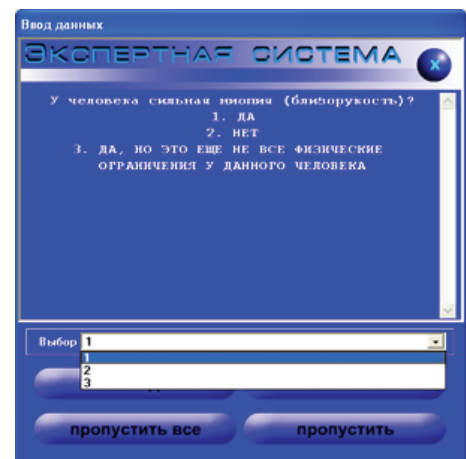recommendations

Fig. 11. ES screen form, making a positive
choice

Thus, one of the scenarios for the ES operation for ensuring the ergonomics of the PC user interface was realized using the example of the "severe myopia"scenario.
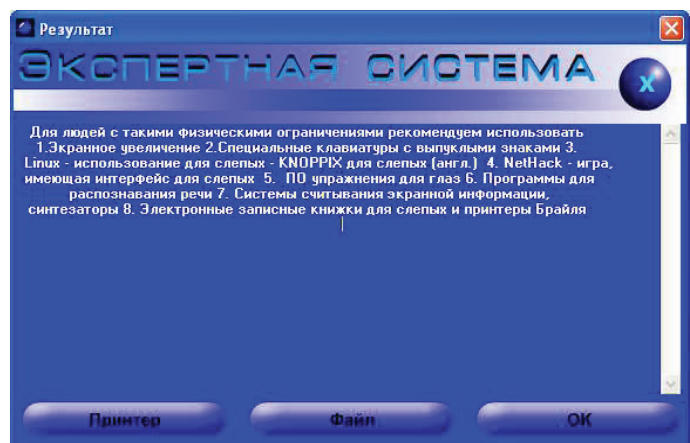

Fig. 12. ES screen form, issuing recommendations on the use of a
set of software and hardware

Table 1

Classification of physical limitations in humans

Physical limitation classes	Physical limitation subclasses	Physical limitations	Solution
visual disorder	myopia	Mild myopia	On-screen zoom (ZoomText program)
		Moderate myopia	1. On-screen zoom (ZoomText program). 2. Special keyboards with raised characters. 3. ScientificLinux OS - use for the blind. 4. Software exercises for the eyes. 5. NetHack - a game with an interface for the blind
		Severe myopia	1. On-screen zoom (ZoomText program). 2. Special keyboards with raised characters. 3. Programs for speech recognition. 4. Systems for reading screen information. 5. Programs for speech synthesis. 6. Braille display and printer. 7. ScientificLinux OS – use for the blind. 8. Virtual touch system (VTS). 9. Machines that read. 10. Electronic notebooks for the blind. 11. NetHack is a game with an interface for the blind. 12. Programs reminding of eye exercises
	hyperopia	Mild hyperopia	On-screen zoom (ZoomText program)
		Moderate hyperopia	1. On-screen zoom (ZoomText program). 2. Special keyboards with raised characters. 3. ScientificLinux OS - use for the blind. 4. NetHack is a game with an interface for the blind. 5. Softwarw exercise for the eyes
		Severe hyperopia	1. On-screen zoom (ZoomText program). 2. Special keyboards with raised characters. 3. Programs for speech recognition. 4. Systems for reading screen information. 5. Programs for speech synthesis. 6. Braille display and printer. 7. ScientificLinux OS – use for the blind. 8. Virtual touch system (VirtualTouchSystem - VTS). 9. Machines that read. 10. Electronic notebooks for the blind. 11. NetHack is a game with an interface for the blind. 12. Programs that remind of the timing of eye exercises
	glaucoma	open-angle	1. High quality monitor. 2. Screen zoom (ZoomText program). 3. Special keyboards with raised characters
		closed-angle	1. High quality monitor. 2. Screen zoom (ZoomText program). 3. Special keyboards with raised characters
	strabismus	concomitant	1. High quality monitor. 2. Programs that remindof the timing of eye exercises
		paralytic	1. High quality monitor. 2. Programs that remindof the timing of eye exercises
	amblyopia	Dysbinocular	1. High quality monitor. 2. Program for photostimulation "photostimulation" from the center "NE-BU-LEI-KA"
		hysterical	1. High quality monitor. 2. Program for photostimulation "photostimulation" from the center "NE-BU-LEI-KA"
		Obscuration	1. High quality monitor. 2. Program for photostimulation "photostimulation" from the center "NE-BU-LEI-KA"
	blindness	–	1. Special keyboards with raised characters. 2. Programs for speech recognition. 3. Systems for reading screen information. 4. Programs for speech synthesis. 5. Braille display and printer. 6. ScientificLinux OS - use for the blind. 7. NetHack is a game with an interface for the blind. 8. Virtual touch system (VTS). 9. Machines that read. 10. Electronic notebooks for the blind. 11. NetHack – a game with an interface for the blind

Continuation of Table 1

hearing disorder	Hearing loss I degree	–	High quality headphones
	Hearing loss II degree	–	High quality headphones
	Hearing loss III degree	–	1. High quality headphones. 2. Subtitling system
	Hearing loss IV degree	–	1. Subtitling system. 2. Using a Windows OS feature - replacing audible alarms with on-screen indicators. 3. Software for the deaf COMMplements from Peacock Communications Inc
	deafness	–	1. Subtitling system. 2. Using a Windows OS feature - replacing audible alarms with on-screen indicators. 3. Software for the deaf COMMplements from Peacock Communications Inc
Speeh disorder	Impaired speaking	Speech disorder	1. Systems of speech data output. 2. Device of the "Light pen" type
		Systemic speech disorders	1. Systems of speech data output. 2. Device of the "Light pen" type
Muscu-loskeletal disorders	Temporary (mechani-cal damage)	Dislocations	1. Touchpad. 2. Alternative input devices. 3. Main mice controlled by head movement
		Fractures	1. Touchpad. 2. Alternative input devices. 3. Main mice controlled by head movement
	long term disruption	Rachiocampsis	Software - a set of physical exercises for the spine
		Dystrophy	1. Touchpad. 2. Special small keyboards
		Paralysis	1. Sensory devices powered by impulse of possible movement. 2. Main mice controlled by head movement
		Joint diseases	1. Special small keyboards
	Violation of the or-gans of the musculo-skeletal system	Serious motor impairment	1. Special small keyboards. 2. Regulation of the speed of repeated pressing and blocking of the modifying key (SHIFT, Ctrl, etc.). 3. On-screen keyboard (for very severe motor impairments). 4. Auto click function (for users who can't press a key)
		Right hand missing	1. Special small keyboards. 2. Software for left-handers
		Left hand missing	Special small keyboards
		The absence of both hands	1. Special large keyboards adapted to control the computer with the toes. 2. Main mice controlled by head movement
		Lack of lower limb (s)	Standard software and hardware set

7. Discussion of the results of the development of a method for ensuring the ergonomics of the Web interface

When determining the effectiveness of the object-oriented approach to the process of knowledge processing in the expert system (ES) of the ergonomics of the PC user interface, which follows from the results obtained [9, 10], it should be noted that the application of this approach allows the development of well-structured, reliable in operation, software systems are easily modified by reducing the complexity of software and increasing its reliability, ensuring the possibility of modifying individual software components without changing its other components and the possibility of reusing individual components. Obviously, such an approach is acceptable for effective modeling of knowledge of the human thinking process, because thanks to the use of the object-oriented approach, this knowledge is represented as a set of objects, each of which is an instance of a certain class, forms a hierarchy of inheritance.

In contrast to the studies in [17–19], where all methods for developing interface ergonomics are inherently subjective and do not rely on formalized assessment tools, despite the available results on the development of these methods to improve the quality and convenience of interfaces, this result of the development of an expert Ergonomics systems of the Web-interface for a customer of a virtual instrument-making enterprise allow for a special selection of hardware and software necessary for the full-fledged work of a person with disabilities. This becomes possible thanks to the use of mathematically sound methods and analysis of the usability of methods and means of creating an ES at all stages of development, contributes to an increase in the conversion and quality of the resource.

The use of the subjective opinion of users and experts on the ergonomics of interfaces in studies [12, 13] is explained by the rather high complexity of formalizing the evaluation criteria, since among them there is a psychological and artistic aspect. By using the methods of mathematical analysis in the presented work, a meaningful structure of the concept of interface quality has been developed, adapted by virtual instrument-making enterprises for customers with disabilities, which differs from the existing ones by the presence of analysis elements in such dimensions: linguistic hierarchical production model and groups of controls.

The practical value of the results, in contrast to the works [1, 2], lies in the fact that the implementation of a

theoretical study allowed the development and implementation of a virtual instrument-making enterprise SPE«KIATON» (Kharkiv, Ukraine) a software system for supporting research of ergonomic interface indicators for users with restricted abilities. By focusing developers on the goals and expectations of customers with disabilities, a 60 % reduction in the cost of the Web interface in the early stages of development was achieved, a 25 % decrease in user training time, a 60 % decrease in the number of technical support calls, an increase in the number of virtual instrumentation customers and enterprises, as well as improving the psychological state of users of the software product.

Such conclusions can be considered expedient from a practical point of view, since they allow building the system under study in such a way that a person manually enters input data into the system and receives recommendations based on the analysis of these data. After all, the number of hardware and software for people with disabilities is growing, which requires constant updating of the ES database and knowledge base.

The disadvantage of logical-linguistic models is that knowledge is difficult to structure, but for the end user, this model is the most understandable when solving the problem of representing a complex sentence. As the study has shown, the optimal model for representing knowledge based on a complex sentence is a logical-linguistic model that allows to clearly understand the meaning of a sentence and preserves all semantic connections.

Knowledge in expert systems is a description of algorithms for solving problems in a problem area. However, knowledge itself, even those that are proven practice results of cognition of activities, are actually unproductive, since they generate a type of chaotic information sphere, and also the usually limited set of controls for designing forms of the Web interface indicate the difficulties of interaction between the software and the user. This is manifested primarily in the fact that the current version of the HTML language supports only a limited set of controls (SC) and does not offer support for complex interactions that are often used in desktop applications, such as a calendar, wizards, bookmarks, toolbars, contextual menus, and so on. While these controls can be developed using JavaScript and CSS, the lack of native browser support leads to a variety of implementations with inconsistent representations and ways of working with them. In summary, the limited set of available controls makes it harder to support the interaction of a disabled virtual instrumentation customer with Web interfaces. This uncertainty imposes certain restrictions on the use of the results obtained, and can be interpreted as disadvantages of this study. The inability to remove the named restrictions within the framework of this study creates a potentially interesting direction for further research. In particular, they may focus on developing built-in universal browser support for users with disabilities and improving the way they work with them.

8. Conclusions

1. The conducted studies analyzed the usability of methods and tools for developing ES, which consist in ensuring the convenience of using the interface of a virtual instrument-making enterprise for people with disabilities and require developers to establish the semantics of the subject area of interconnections of complex objects and their relationships, gives an idea of the algorithm of the investigated development of improvement ergonomics of the Web interface. Due to this, it can be argued that the algorithm of the developed method has a complex hierarchical metasemantic network, in which the properties of the first set are inherited by the second set, and is a collection of facts and statements from the database.

The study also identified the physical shortcomings of customers of a virtual instrument-making enterprise and created a knowledge base of an expert system to provide a convenient representation of this body of knowledge as a whole and any part of it. This is manifested in the fact that the knowledge base management system provides the presentation and processing of a model comparable in terms of its complexity with the model used by human consciousness.

2. Features of the mathematical modeling of the ES ergonomics of the interface are in the creation of a logical-linguistic hierarchical model, taking into account the hierarchical relationships between the input variables of the system. With the help of the logical-linguistic hierarchical production model, the hierarchical relationships between the input variables of the system were taken into account, made it possible to structure the developed method. After all, the logical-linguistic model controls the integrity of the sentence, clearly describes the content of the sentence and provides an accessible representation of knowledge.

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