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EXPERT EVALUATION OF QUALITY CRITERIA FOR HUMAN-MACHINE INTERFACES IN AUGMENTED REALITY

Abstract. In today's world of widespread augmented reality technologies, ensuring high-quality user interfaces that determine the effectiveness, safety, and reliability of user interaction with the digital environment is becoming particularly important. **The subject of the study** is the methods and criteria for evaluating the convenience, clarity, stability, and functional completeness of the augmented reality system interface for unmanned aerial vehicle operators as part of an explosive hazard monitoring system. It is important to analyze the implementation of methods such as evaluation using quality metrics, focus group surveys, and expert surveys, based on a comparison of their advantages and disadvantages that become apparent under certain conditions. **The purpose of the work** is a comprehensive expert evaluation of the augmented reality interface using a structured checklist. The evaluation covered self-descriptiveness, controllability, error protection, consistency, aesthetic integrity, responsiveness, reliability of information presentation, and other criteria recommended by relevant international standards. **Tasks**: to develop an augmented reality interface; to identify possible quality criteria, taking into account the characteristics of human-machine systems of a certain type; to propose a list of questions for expert surveys based on the identified quality criteria; to conduct expert surveys. **Research results:** a mock-up of an augmented reality interface for human-machine interaction between the operator and unmanned aerial vehicles was created, a list of criteria for evaluating the quality of augmented reality systems was formed, and an expert survey was prepared and conducted to evaluate the quality of the proposed interface. The survey results are presented in the form of a radial diagram, which allows you to clearly identify the advantages and disadvantages of the interface, as well as to form priorities for its further improvement. **Conclusions.** The expert assessment method used is an effective tool for identifying problems in user interaction with augmented reality and for outlining areas for improving the quality of the interface. The results obtained can be used to further modernize the system, optimize the structure of information reproduction, and create a more intuitive, safe, and ergonomic user environment.

Keywords: augmented reality; quality criteria; human-machine interfaces; expert assessment; monitoring systems.

1. Introduction

Augmented reality (AR) technology is widely integrated into modern industrial and non-industrial information systems as the latest method of human-machine interaction with the aim of improving efficiency, safety, and ease of use [1–3]. AR applications cover manufacturing, transportation, education, medicine, defense, and a range of consumer services, where high-quality visualization and rapid information retrieval significantly affect task accuracy and reduce user errors. Such a high level of interest and growing involvement create a need for models, criteria, and formalized methods for evaluating the quality of proposed AR interfaces.

As the technology spreads, so do the requirements for its ergonomics, reliability, and compliance with international standards, in particular ISO 9241 and ISO/IEC 25010, which regulate the quality indicators of interactive systems. In the context of augmented reality, criteria such as comprehensibility, intuitiveness, cognitive load, stability of visual elements, and correctness of spatial positioning are of particular importance. The lack of a systematic approach to evaluating these parameters complicates the development of effective AR solutions and limits the possibility of their improvement.

In this regard, it is important to develop a list of quality criteria for expert evaluation of AR interfaces, which will allow quantifying the quality level of the system and comparing different options for its implementation. Such an evaluation creates a basis for identifying critical shortcomings, determining the level of compliance with quality requirements, and forming recommendations for optimizing the design of AR interfaces.

2. Analysis of scientific publications and formulation of the research problem

In one of the previous publications [4] by the authors of this work, an analysis of the state of research was carried out and a review of the methods of assessing the quality of systems available at that time was made. The article concluded that most of the proposed methods are based on evaluating the quality of AR systems, since this indicator is the easiest way to assess the attractiveness of the software product being developed for the user. Most often, the heuristic research method is used for evaluation. This choice of evaluation methodology is due to the fact that the quality of use is a subjective characteristic, and the use of the same subjective evaluation method seems logical.

In more recent studies, this trend continues, although the list of evaluated indicators has been significantly expanded. Thus, in works [5–7], physical, mental, and time loads, as well as the efforts and productivity of the group of respondents, are taken into account along with SUS indicators. The results obtained using this approach can be considered more accurate, since it takes into account the impact of AR on the physical and psychological state of the respondents, which is not characteristic of classical methods of evaluating quality of use.

Works [8, 9] consider various options for assessing the quality of AR, mainly focusing on the visual aspect of this technology. Physical and mental load are not taken into account here, but quality indicators such as adaptability, content quality, aesthetics, immersion, etc. are considered. Of course, these criteria are important for human-machine systems with a high level of immersion, which includes augmented reality, but they ignore technical factors and the possible consequences of prolonged use of AR in the form of deterioration of physical and emotional states.

It is also worth highlighting study [10], which evaluates the safety of using systems with AR interfaces on the same hierarchical level as user satisfaction indicators. This quality criterion should be one of the key criteria for human-machine interaction systems with augmented reality, since they have a direct impact on the perception of the environment, but in most studies it is ignored. At the same time, this work lacks criteria for assessing physical and mental stress, as well as the visual component.

In general, it can be concluded that significant progress has been made in recent years in assessing the quality of human-machine AR interfaces, but in the vast majority of cases, existing methods are used without taking into account the specifics of augmented reality. Therefore, determining key criteria for a comprehensive assessment of AR quality is a relevant scientific and practical task. This task is especially important for human-machine systems in which operators control the use of single unmanned aerial vehicles (UAVs), swarms of UAVs, and fleets that combine different swarm systems, where the significant dynamics of flight control require quick and accurate decisions. This applies, in particular, to unmanned systems for humanitarian demining, technical inspection, etc. [11–13]. The integration of AR into such interfaces is a new approach that requires appropriate research, in particular, on the assessment of interface quality and the impact of AR on the operator and the system as a whole.

3. Purpose and objectives of the study

The purpose of this study is to develop a set of quality criteria for human-machine augmented reality systems and to conduct an expert evaluation of the proposed interface. The study was aimed at identifying the strengths and weaknesses of the interface, identifying potential problems in user interaction with the system, and developing quantitative indicators that can be used for further design optimization. To this end, a 10-point expert survey was used, which made it possible to obtain comparable and interpretable results across a wide range of criteria, including functional completeness, responsiveness, self-descriptiveness, safety of use, aesthetic integrity, and others. The data obtained provided the opportunity for a comprehensive analysis of the interface and the formation of recommendations for its improvement.

4. Research materials and methods

4.1 Explosive object monitoring system

Since the human-machine interface cannot exist as an object separate from the system, the authors of the study decided to develop the architecture of the explosive object monitoring system shown in Fig. 1, where AR is considered as a means of visualizing information for UAV operators and ground robotic complexes (GRC). Such a system, as noted, is an example of human-machine systems with rapidly changing application dynamics.

The system includes a central server and databases responsible for processing and storing critical information about the geographical coordinates of areas potentially contaminated with explosive objects, historical data on the presence of mines, maps of demined areas, and telemetry data obtained from UAVs and GRCs. This data is processed by a central server, which transmits it to the control center and control station in real time.

The control center is the main analytical hub of the system, which manages the entire operation, monitors the status of drone swarms and demining teams, and analyzes the data received for quick decision-making.

Here, records, reporting systems, access lists (if necessary) are kept and confidential materials are controlled.

The demining group works directly in the area of operation, but thanks to augmented reality glasses, it receives critically important information that increases their level of safety. However, the AR interface for the demining group is not considered in this work.

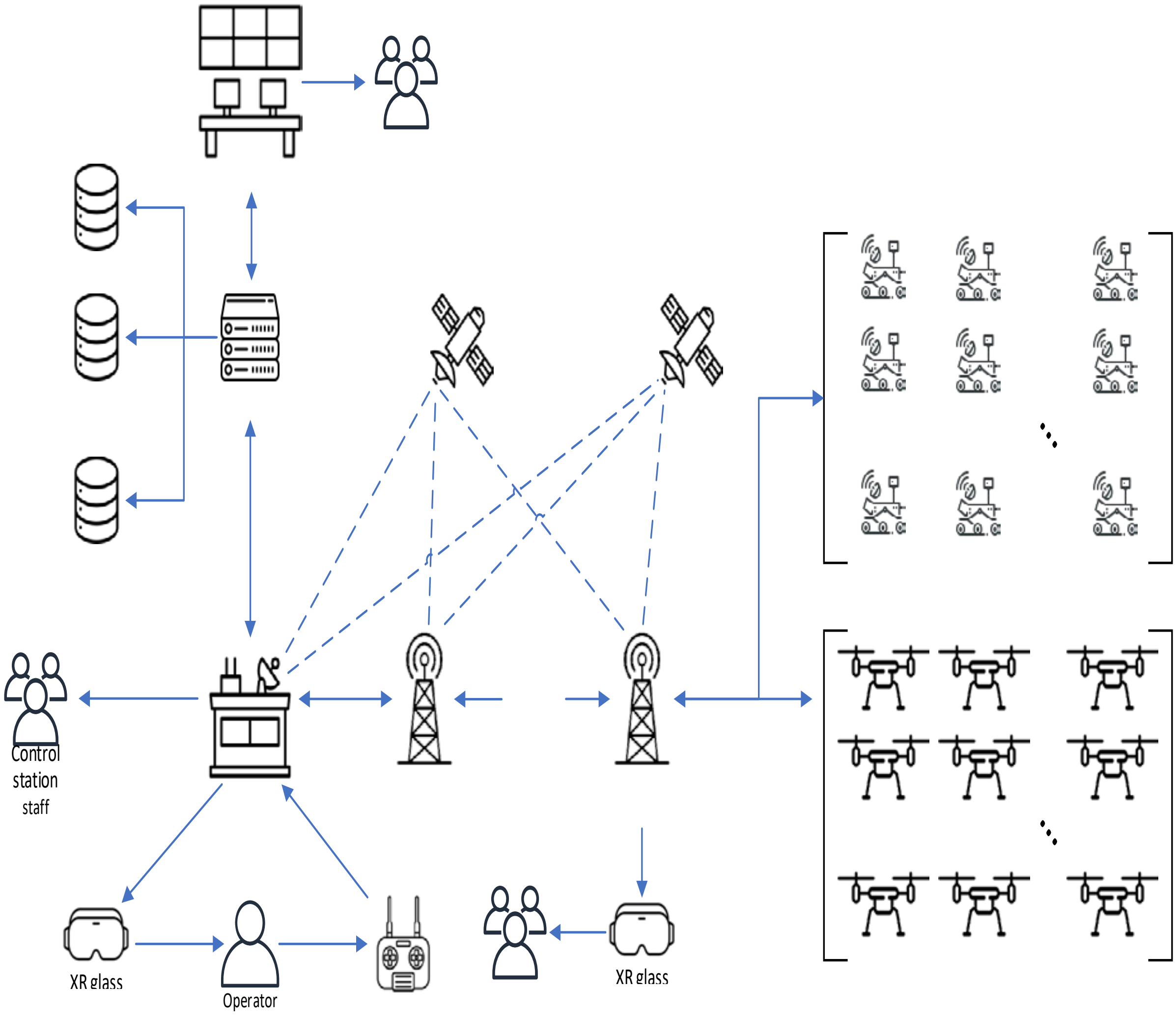

Fig. 1. Architecture of the explosive objects monitoring system

The control station is located in close proximity to the area under investigation and serves as a local control and maintenance point for UAVs and GRCs. It receives data from the server, provides communication with operators, and controls the interaction of drone swarms.

Operators at the control station work with remote controllers, which allows them to control individual UAVs or GRCs in critical situations, receive and analyze video streams in real time, and change flight routes according to new data.

Operators use augmented reality glasses to display AR interfaces, allowing them to view mine threat maps, control UAVs and GRCs, and receive important information.

4.2 Augmented reality interface for drone operators

Although augmented reality interfaces are quite common, there are very few examples of their use for interacting with UAVs. This can be explained by the fact that research in this area of AR use is still in its infancy.

For example, [14] presents an AR interface for mobile devices that allows you to control a fleet of UAVs using virtual manipulators on a touch screen. However, there is a significant drawback in that the operator must constantly maintain visual contact with the drone to control its flight direction and ensure communication with the mobile device.

This necessity is caused by the fact that the window displaying the video stream received from the UAV occupies less than 10% of the screen space and is partially covered by virtual controls. For mobile devices with serious limitations in display size and resolution, such a small display area makes it almost impossible to view information from the UAV.

This option of using AR to control a UAV can be used for personal purposes, but it is not suitable for performing tasks in monitoring systems.

In [15], it is proposed to use augmented reality to control UAVs from a first-person perspective using augmented reality glasses. A remote control is used to control the flight of the UAV, while information from the drone's cameras is displayed on virtual windows.

This option seems much more convenient in terms of control, but does not allow for the control of a fleet of UAVs. Also, in this version of the AR interface, there are no control elements such as charge level, altitude, speed, etc. For these reasons, it is not possible to use this option for monitoring systems.

In [16], an option is proposed that is positioned as an interface with augmented reality elements for UAV control. Unlike the previous study, this one has all the necessary indicators for controlling an unmanned aerial vehicle. However, the interface still has a number of drawbacks, namely the small size of the elements responsible for displaying the video stream from the UAV and the flight map, as well as the inability to control a group of unmanned aerial vehicles.

There is also a conceptual question of whether the proposed human-machine interaction system can be considered to contain augmented reality elements, since all virtual control elements are located in a 2D plane, although the classic definition of AR[17] requires them to be placed in 3D. Based on the above-described options and shortcomings of existing AR interfaces, it is advisable to present our own design option.

Fig. 2 shows a mock-up of one of the developed drone control interfaces with built-in augmented reality elements. This interface design aims to expand the operator's capabilities in the process of human-machine interaction.

The concept of augmented reality provides the possibility of tactile control of individual elements of human-machine interfaces, which theoretically simplifies and speeds up switching between the control of individual units of UAV swarms and GRC.

This, in turn, can contribute to improving the quality of use of such interfaces and enhance the user experience of operators, while preserving the basic elements of classic human-machine interfaces of unmanned aerial vehicles.

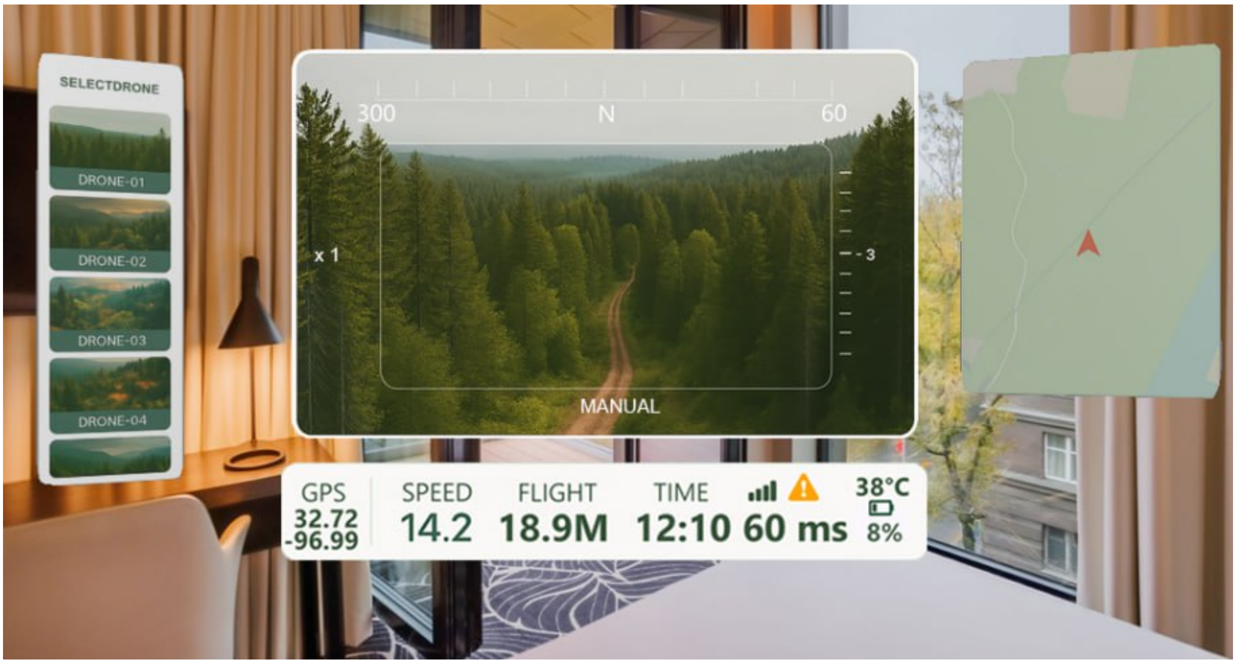

Fig. 2. Augmented reality interface layout for drone operators

The proposed augmented reality interface for the UAV and GRC operator consists of four virtual windows, each of which performs a separate function:

– the central interface window is the main one and is used by the operator to display the video data stream coming from the UAV and GRC. In addition to the images from the drones, the screen displays controls such as a compass for tracking the direction of movement and an indicator of the angle of inclination of the video camera from which the image is transmitted. Other controls are not displayed on this screen in order to reduce the number of factors that distract the operator during the task and to increase the field of view;

– to the right of the main window is a window with a map for monitoring the flight route;

– the bottom panel displays information necessary for the operator about the technical condition of the controlled UAV or GRC, its speed and altitude, operating time, position in space, etc. These controls are placed in a separate window to free up as much workspace as possible on the main screen;

– the window on the left is used for visual monitoring of the other drones in the system and quick switching between them. This is the only element of the augmented reality interface that involves touch interaction. This window is used not only to display the video stream from other drones in the system, but also to quickly switch between them using gesture controls. When you tap on an element in the window, control switches to the corresponding drone. You can also use gesture controls in the window to scroll through the list of drones and switch between the UAV and GRC tabs. This interaction mechanism is designed to speed up switching between different types of drones and the drones themselves. Other interface elements do not allow such freedom in interaction with them. This restriction is implemented to reduce the risk of errors during drone control due to incorrect or mistaken gestures.

Thus, the augmented reality human-machine system described in Fig. 2 allows the drone control elements to be broken down into separate windows. Traditionally, this approach requires multiple monitors, but augmented reality has no such limitations and can use virtual monitors placed in the operator's field of view. These windows can be placed in any order and at any convenient point, changed in size and orientation, removed if necessary, and subsequently reopened. Such flexibility in use should have a positive impact on the mobility of the system and the operator's user experience.

Thus, the proposed interface has a number of significant advantages over the solutions presented in [14–16]. Unlike the analogues considered, the interface in Fig. 2 provides control based on information received directly from the UAV camera and supplemented with elements in the form of a compass displayed in the central window and a map of the area displayed in a separate window. The operator will not need to maintain constant visual contact with the controlled device, thereby limiting the area of monitoring tasks. Also, in the proposed version, telemetry data, including GPS coordinates, speed, altitude, flight time, image delay, temperature, signal strength, and battery status, are consolidated into a single compact panel, which should reduce visual noise and cognitive load thanks to better workspace organization. Integrated warnings about the current status of the controlled UAV are intended to further improve the operator's decision-making, and thus should reduce training time and increase the efficiency of real-time information processing compared to the solutions described conceptually in [14, 16].

The scientific novelty of this approach to interface design lies in the optimization of information presentation through the compact grouping of key telemetry indicators and auxiliary functions into separate windows, which frees up as much of the main workspace as possible from information noise. This differs from existing solutions [14–16], where telemetry elements are placed on the main screen, reducing the visibility of the video stream. Reorientation to a full-fledged AR environment, where functional elements are placed in space as separate virtual windows, eliminates physical limitations of the workspace and provides the ability to scale, rearrange, and personalize the interface. Also, unlike the known ones, the developed layout provides for the use of gesture interaction between unmanned aerial vehicles. The results obtained create the prerequisites for the further development of multi-window AR-based human-machine interaction systems focused on scalable control of UAV and GRC groups.

4.3 Quality criteria for AR interfaces

A list of criteria for further expert evaluation of the quality of augmented reality human-machine interfaces was prepared based on a combination of subjective and objective criteria. Subjective criteria include indicators describing ease of use, perception, intuitiveness, and the interface's compliance with user needs, formed in accordance with ISO/IEC 25010:2011 [18], ISO 9241-210:2019 [19] and the arc42 conceptual quality model [21]. Objective technical criteria that ensure reliability, correct display of information, and safe interaction were selected in accordance with the requirements of NUREG-0700 [20] and the recommendations of IEEE P2048.101 [23]. The coordination of these sources made it possible to form a balanced and comprehensive set of indicators (Table 1), suitable for systematic analysis and comparative evaluation of augmented reality interfaces.

Table 1. *List of quality criteria for AR interfaces*

№	Name	Source
1	Functional Completeness	[18, 19]
2	Functional Appropriateness	[18]
3	Time Behaviour	[18, 20]
4	Resource Utilization	[18]
5	Learnability	[18, 19]
6	Faultless	proposed
7	Reactivity	proposed
8	User Error Protection	[18, 19]
9	Self-descriptiveness	[18, 19]
10	Safety	[18]
11	Durability	[21]
12	Hazard Warning	[18]
13	Predictability	[21, 22]
14	Suitability	[18]
15	Personalization	[21]
16	Coherence	[21]
17	Conciseness	[21, 20]
18	Controllability	[22, 19]
19	Aesthetic Integrity	[22]
20	Visual Accuracy	[22]
21	Readability	[21, 20]
22	Aesthetics	[19]
23	Alignment Accuracy	[23]
24	Frame Rate	[23]
25	Latency	[23]
26	Cognitive Load	proposed
27	Stress	[6, 7]
28	Fatigue	[6, 7]
29	Realism	proposed
30	Unambiguity	[20]
31	Distinguishability	[20]
32	Visibility	proposed
33	Interactivity	[8]

Functional completeness – the degree to which the set of functions covers all the defined tasks and goals of the intended users.

Functional Appropriateness – the degree to which the set of functions contributes to the fulfillment of the defined tasks and goals.

Timeliness – the degree to which the response time of the system during the performance of its functions meets the requirements.

Resource utilization is the degree to which the number and types of resources used in performing its functions meet the requirements.

Learnability is the degree to which the functions of a product or system can be learned for use by specific users within a specified period of time.

Faultless is the degree to which the interface influences the accuracy of user actions performed using the augmented reality system.

Reactivity is the degree to which the interface influences the speed of user response in specific situations.

Error protection – the degree to which the system prevents user errors during operation.

Self-descriptiveness – the degree to which the product provides relevant information necessary for the user to understand its capabilities and use without excessive interaction with the product or other resources such as documentation, support services, or other users.

Safety – the degree to which a situation that endangers life, health, property, or the environment can be avoided.

Durability – the degree to which a system is capable of remaining useful over a long period of time.

Hazard warning – the degree to which the system is capable of warning of unacceptable risks so that timely action can be taken to ensure the user's safety.

Predictability – the degree to which the consequences of user actions can be predicted, including the current state of the system.

Suitability – the degree to which functions are provided that meet the stated and implied needs of the intended users when used under the specified conditions.

Personalization – the degree to which the product can be modified or customized to suit the user's personal preferences.

Coherence – the degree to which interface elements are logically and aesthetically organized or integrated.

Conciseness – the degree to which the user interface is able to convey the necessary information concisely, clearly, and without unnecessary elements, but without sacrificing content or func*tionality*.

Controllability – the degree to which the user feels in control of the interface elements.

Aesthetic integrity – the degree to which the interface elements visually correspond to a single style.

Visual Accuracy– the degree to which the interface elements are free of visual, stylistic, or spelling errors.

Readability – the degree to which interface elements are legible and easy to read.

Aesthetics – the degree to which the interface provides a pleasant and satisfying interaction.

Alignment accuracy is the degree to which a virtual object deviates from its intended display location.

Frame rate is the degree to which the image refresh rate meets requirements.

Latency is the degree to which there is a delay between the user's movement and the image refresh.

Cognitive load – the degree to which the cognitive load on the user increases as they use augmented reality interfaces.

Stress – the degree to which the user's stress or tension level increases as they use augmented reality interfaces.

Fatigue – the degree to which the user's fatigue increases as they use augmented reality interfaces.

Realism – the degree to which the augmented reality interface reflects elements of the surrounding environment.

Unambiguity – the degree to which ambiguous interpretations of the purpose of augmented reality interface elements are not allowed.

Distinguishability – the degree to which individual interface elements, icons, and symbols differ from each other.

Visibility – the degree to which virtual elements stand out against the background of the real world.

Interactivity – the degree to which direct interaction with augmented reality elements is possible, including through touch, sound, and vibration.

4.4 Expert poll

To validate the results obtained, they must be verified within the framework of an experiment to evaluate the quality of the human-machine interaction system. In quality engineering, there is a wide range of possible methods, but in the context of augmented reality, the following are the most widely used:

– evaluation using metrics;
– focus group surveys;
– expert surveys.

At this stage of the research, it is not possible to use metric evaluation, as this method requires a fully formalized quality model and a working prototype of the system. It is also necessary for all participants in the evaluation process to have access to a device for displaying interfaces, which in this case are augmented reality glasses. This makes the metric evaluation method unsuitable at this time. The focus group survey method is also unsuitable for us, as this method involves obtaining feedback directly from the end users of the product being evaluated.

The expert survey method is the most acceptable because it allows us to evaluate subjective indicators of human-machine interfaces from the point of view of people with different levels of professional experience in using AR. This makes it possible to identify existing design flaws and improve the quality of the interface at the design stage.

Google Forms was chosen as the tool for conducting the expert survey because this service combines the accessibility, convenience, and functionality necessary for evaluating interfaces, and also guarantees that all responses are stored in the cloud for further statistical processing. This minimizes manual work, reduces the risk of errors, and makes the results immediately ready for analysis.

To evaluate the quality of the proposed augmented reality interfaces using the expert assessment method, the following questions were compiled based on the criteria presented in Table 1:

1) Can such an interface facilitate the performance of all the operator's anticipated tasks?
2) Can such an interface affect the accuracy of the operator's actions?
3) Can such an interface affect the operator's reaction speed?
4) Will it be possible to master such an interface in a short period of time?
5) Is such an interface intuitive?
6) Does such an interface allow avoiding situations that are dangerous to the physical health of the operator or the environment?
7) Can such an interface remain relevant for a long period of time?
8) Does the presence of augmented reality affect the moral aging of the interface?
9) Can such an interface warn the operator of possible risks?
10) Can the interface elements be customized according to the operator's personal preferences (the location of AR elements in space)?
11) Is such an interface capable of conveying the necessary information in a concise, understandable form?
12) Do the interface elements correspond to a single visual style?
13) Does this AR interface improve the realistic representation of the environment?
14) Does such an interface prevent ambiguous interpretation of the purpose of elements?
15) Do the AR elements of the interface stand out against the background of the real world?

The process of expert evaluation of the interface by means of a checklist survey in Google Forms using a 10-point scale consists of several consecutive stages that ensure the reliability, representativeness, and reproducibility of the results. First, an expert group is formed, consisting of specialists with relevant expertise in the field of human-machine interfaces or augmented reality. Based on the evaluation criteria, a checklist is created that includes indicators that can be measured quantitatively: interface clarity, user load, navigation intuitiveness, stability, visual clarity, etc. Each item on the checklist is formulated unambiguously and relates to only one criterion.

Next, a questionnaire is constructed in Google Forms based on this checklist. For each question, the answer type "Linear scale" is selected with a range from 1 to 10, where 1 means minimum compliance with the criterion and 10 means maximum compliance. For greater accuracy, a short text explanation is added (for example, "1 – absolutely not", "10 – yes, completely"). The survey may contain additional open-ended questions for qualitative comments from experts.

The use of a 10-point scale for evaluating user interfaces is appropriate given its increased sensitivity and analytical suitability. Unlike 3-, 5-, or 7-point scales, the 10-point scale provides a wider range of gradations, allowing respondents to more accurately reflect their perception of the convenience, clarity, or effectiveness of the interface. This scale reduces the likelihood of the "central tendency" effect, where participants tend to choose the average value, and promotes more differentiated assessments. In addition, the 10-point scale is often considered quasi-interval, which allows for the correct application of statistical analysis methods, including the calculation of mean, variance, correlations, and regression models.

This increases the accuracy of the results and provides a better analytical basis for researching the quality of user interfaces.

After creation, the form is sent to experts, and their responses are automatically collected in a spreadsheet. At the final stage, a statistical analysis is performed: the mean, median, standard deviation, and range of ratings for each criterion are calculated. A comparative analysis between experts or between different versions of the interface can also be performed. The results are interpreted to identify the strengths and weaknesses of the interface and form the basis for further recommendations for its improvement.

A group of 13 experts was involved in the quality assessment, consisting of specialists in the area of information technology with varying levels of experience in the use, development, and evaluation of human-computer interfaces. The vast majority of respondents are men aged 24 to 80, most of whom are graduate students. Almost half of the experts have a high level of expertise in evaluating the quality of human-machine systems, including augmented reality interfaces. Table 2 provides detailed characteristics of the expert group.

Table 2. *Characteristics of the expert group*

Indicator		Value	%
Gender	Male	11	84,62
	Female	2	15,38
Age	Under 30	5	38,46
	30 to 45	5	38,46
	Over 45	3	23,08
Position	Professor	4	30,77
	Associate professor	1	7,695
	Postgraduate student	7	53,84
	Developer (3 years of experience)	1	7,695
Level of expert experience in analyzing interface quality	Low	3	23,08
	Medium	4	30,77
	High	6	46,15

5. Research results

The results of the expert assessment presented in Fig. 3 demonstrate an uneven distribution of interface quality indicators across a range of metrics. The highest scores were given to criteria such as self-descriptiveness, trainability, functional completeness, and responsiveness, which were rated predominantly at 8 points. This indicates that the interface is intuitive, easy to learn, and capable of responding quickly to user actions. High scores were also observed for accuracy, visibility, realism, and aesthetic integrity, indicating an overall positive perception of the visual and behavioral components of the system.

Moderate ratings (7–8 points) were given to criteria such as unambiguity, conciseness, personalization, and relevance, indicating that there is room for improvement, but without critical comments from experts. The lowest scores were recorded for hazard warnings and durability, which were rated between 4 and 5 points. This indicates that the system does not pay sufficient attention to safety aspects and specific mechanisms to ensure its stable functioning in the long term. A slightly below-average level was also recorded for safety of use, which may indicate a need for additional measures to inform users or reduce potential risks.

Overall, the interface demonstrates high levels of usability and clarity, but requires further optimization in areas related to security, stability, and long-term operation.

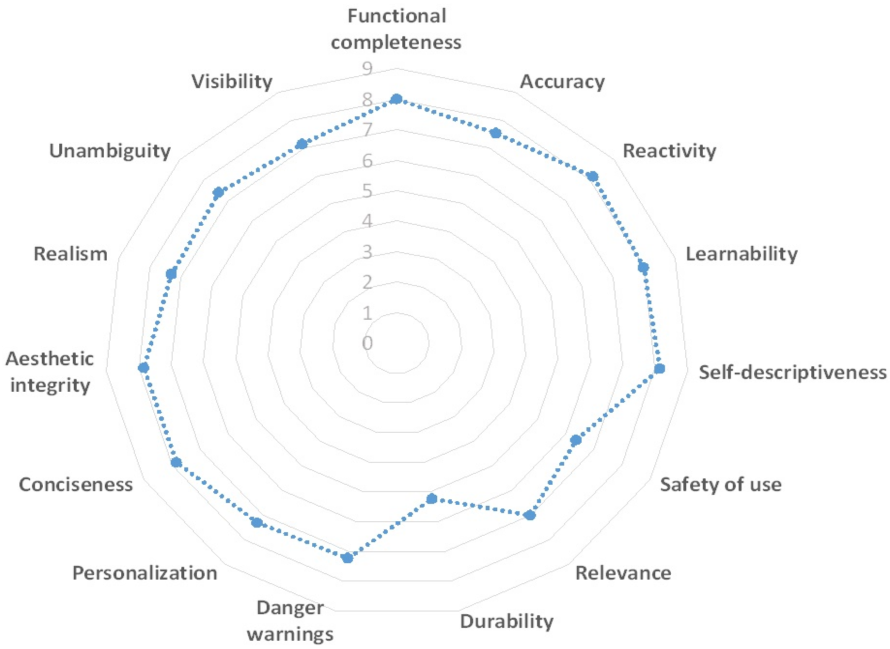

Fig. 3. Poll results diagram

6. Conclusions and further research

This study proposed a list of quality criteria for evaluating augmented reality human-machine interfaces using the example of interfaces for drone operators. The quality criteria were formed based on ISO/IEC 25010:2011, ISO 9241-210:2019, NUREG-0700, IEEE P2048.101, and other relevant sources. For the experimental evaluation using the expert survey method, a questionnaire with 15 questions was compiled and presented to 13 experts. The results of the expert assessment showed that the methodology used to analyze the quality of the augmented reality interface based on a structured checklist and a 10-point scale is an effective and valid tool for determining the usability and ergonomics of the system. The obtained assessments made it possible to quantitatively characterize the key parameters of the interface, in particular its clarity, consistency, informativeness, responsiveness, error protection, and aesthetic quality. Analysis of the score distribution diagram showed that most criteria meet an acceptable or high level of quality, but some aspects were identified that require further refinement, in particular, optimization of the structure of information presentation, reduction of cognitive load, and improvement of the stability of visualization elements.

Overall, the results confirm that the proposed approach to expert evaluation is appropriate for augmented reality systems for various purposes and can be used as a basis for the cyclical improvement of interface quality, ensuring their high efficiency, safety, and compliance with modern international standards. Further research may be directed at assessing the impact of the proposed augmented reality interface on the speed and accuracy of decision-making by unmanned system operators. Another important area of research could be the optimization of the structure of information display in the user environment and the development of augmented reality interfaces for the demining group, which also uses augmented reality to work with the explosive object monitoring system.

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ЕКСПЕРТНЕ ОЦІНЮВАННЯ КРИТЕРІЇВ ЯКОСТІ ЛЮДИНО-МАШИННИХ ІНТЕРФЕЙСІВ ДОПОВНЕНОЇ РЕАЛЬНОСТІ

У сучасних умовах активного поширення технологій доповненої реальності особливої актуальності набуває проблема забезпечення високої якості користувацьких інтерфейсів, які визначають ефективність, безпечність і надійність взаємодії користувача з цифровим середовищем. **Предметом дослідження** є методи й критерії оцінювання, спрямовані на аналіз зручності, зрозумілості, стабільності та функційної повноти інтерфейсу системи доповненої реальності для операторів безпілотних апаратів у складі системи моніторингу вибухонебезпечних об’єктів. Важливим є аналіз таких методів, як оцінювання за допомогою метрик якості, опитування фокус-груп і експертне опитування, на основі порівняння їх переваг і недоліків, що виявляються за певних умов. **Мета роботи** – комплексне експертне оцінювання інтерфейсу доповненої реальності з використанням структурованого чек-листа. Оцінюванню підлягали самоописуваність, керованість, захищеність від помилок, узгодженість, естетична цілісність, реактивність, надійність подання інформації та інші критерії, рекомендовані відповідними міжнародними стандартами. **Завдання:** розробити інтерфейс доповненої реальності; визначити можливі критерії якості з огляду на особливості людино-машинних систем певного типу; запропонувати перелік запитань для опитування експертів на основі виокремлених критеріїв якості; провести експертне опитування. **Результати дослідження:** створено макет інтерфейсу доповненої реальності для людино-машинної взаємодії оператора з безпілотними апаратами, сформовано перелік критеріїв для оцінювання якості систем доповненої реальності, а також підготовлено й проведено експертне опитування з метою оцінити якість пропонованого інтерфейсу. Результати опитування подано у вигляді радіальної діаграми, що дає змогу наочно визначити переваги й недоліки інтерфейсу, а також сформувати пріоритети його подальшого вдосконалення. **Висновки.** Метод експертного оцінювання є ефективним інструментом для виявлення проблем взаємодії користувачів з доповненою реальністю й для окреслення напрямів підвищення якості інтерфейсу. Отримані результати можуть бути використані з метою подальшої модернізації системи, оптимізації структури відтворення інформації та створення більш інтуїтивного, безпечного й ергономічного користувацького середовища.

Ключові слова: доповнена реальність; критерії якості; людино-машинні інтерфейси; експертне оцінювання; системи моніторингу.

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