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METHOD FOR CONTEXT-AWARE ADAPTATION OF A VISUAL USER INTERFACE BASED ON ESTIMATING THE DISTANCE TO THE USER

The relevance of this research topic stems from the need to transition from static interfaces to flexible systems capable of dynamically adapting to the user's physical context, particularly to changes in viewing distance, thereby reducing cognitive load and enhancing the comfort of interaction. **The object of the study** is the process of context-aware adaptation of the user visual interface in real time depending on the distance to the user, specifically the typographic parameters of the user interface. **The subject of the study** is approaches to determining the distance to the user based on video stream data. **The aim of the study** is to develop a method for context-aware adaptation of the user interface based on determining the distance to the user, which ensures dynamic scaling of the typographic system to reduce cognitive load and enhance interaction comfort in real time. To achieve the set goal, the following **tasks** were addressed: existing approaches to determining the distance to an object were analyzed, and a method for dynamically changing the scale of the user visual interface was developed, based on the proportional relationship between the distance from the interface to the user and the size of the base typographic unit (point size). To experimentally verify the high accuracy of determining the distance from the visual interface to the user, the study examined the impact of various factors (head tilt in the frontal and sagittal planes, rotation in the horizontal plane), as well as the chosen approach to determining the distance to the object, on the accuracy of distance measurement. **The developed method** ensures the adaptation not only of font size but also of related typographic parameters (line spacing, character spacing, and paragraph indentation). **It has been established** that the approach based on a depth map with approximation provides the most balanced results in terms of accuracy and practical applicability, demonstrating an error of 1.83–3.67% in the range of 30–90 cm. It was also shown that the user's head orientation is a critical factor affecting measurement accuracy, and the maximum error at close range reaches 201.3%.

Keywords: interface; distance; computer vision; depth map; model; method.

1. Introduction

Human-computer interaction is a field of study that examines how people interact with computers and how effective that interaction is. The effectiveness of a human-computer interaction system is determined by high levels of system reliability; ensuring that the user remains productive over the long term; and facilitating the user's professional development.

From the user's perspective, the functional aspects include control (the user's initiative, actions, and commands directed at the system), the interface (the point of contact, which may be graphical, voice-based, tactile, etc.), and user information (data that the system collects and receives about the user through the interface. This may be explicit information or implicit behavioral data), and evaluation (the stage at which the user interprets the system's response received through the interface).

At the same time, traditional visual user interfaces largely remain static and do not account for changes in the physical context of interaction, particularly the distance between the user and the screen. Under such conditions, even a well-designed interface can lose its ergonomic effectiveness, as fixed typographic parameters do not ensure adequate readability and ease of information perception when the user's position relative to the device changes. This is particularly relevant for modern digital systems that operate under variable usage conditions and involve prolonged visual interaction. Such adaptation is particularly significant for users with visual impairments, for whom the ease of perceiving visual information, the readability of text elements, and the ability to automatically adjust display settings directly impact the accessibility of digital services. In this context, dynamic interface adaptation can be viewed as a means of enhancing inclusivity and facilitating the integration of people with visual impairments into the digital environment.

One promising approach to solving this problem is the use of computer vision methods to estimate the distance to the user in real time, followed by dynamic adaptation of display parameters. This approach enables a transition from static interface solutions to context-

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aware systems capable of automatically adjusting not only font size but also related typographic characteristics in accordance with perceptual conditions. In this context, the scientific interest lies in selecting a distance estimation method that ensures sufficient accuracy, resistance to changes in external conditions, and practical suitability for integration into adaptive user interfaces.

Based on the above, it is relevant to develop a method for context-aware adaptation of a visual user interface, in which the estimation of distance to the user is used as a contextual trigger for dynamic scaling of the typographic system.

Previous works dedicated to autonomy and increasing inclusivity for users with disabilities and various types of impairments include [1, 2]. The adaptation of visual interfaces is a logical continuation of these works.

This study focuses on context-aware adaptation of a visual interface based on estimating the distance to the user and dynamically scaling typographic parameters.

2. Analysis of the latest research and publications

Current scientific works propose various classifications of adaptive systems, justify the need for personalization – especially in educational environments – and focus on the user model (their knowledge, goals, and preferences) [3, 4]. Adaptation here refers to a response to the user's internal state (e.g., their level of knowledge). A number of articles propose system architectures that adapt to device characteristics (screen size, memory), providing a logical framework of rules [5–7]. These works also identify the primary beneficiaries of adaptation – people with disabilities (cognitive, visual impairments, etc.) [7–9]. Adaptation here (e.g., changing fonts, simplifying the UI) is viewed as a tool for overcoming accessibility barriers. The works [2, 7] describe adaptation rules but assume that the system already knows the context for activating the rules; however, no attention is given to the technology that activates these rules.

In a broad sense, an adaptive interface involves adjusting information presentation parameters to the user's characteristics and interaction conditions. For visual user interfaces, this specifically means the ability to dynamically change typographic parameters, whereas in a more general sense, adaptation may also encompass auditory, linguistic, or other assistive means of information presentation aimed at improving accessibility for various categories of users [10, 11].

This confirms the relevance of a dynamic approach, where, for example, a user may have no vision problems but be physically far from the screen, which also requires adapting the information displayed on the screen to the physical environment in real time.

Also relevant is the visual modeling of the context-adaptive system to demonstrate the location of the sensory trigger, as well as to prove that unstable adaptation is worse than no adaptation at all. Accurately determining the distance to an object and ensuring smooth font transitions is a critical task and will reduce cognitive load.

Thus, developing a method with increased accuracy in distance determination is not merely a technical task, but an important step toward transforming existing theoretical models of user interface adaptation into practically applicable and reliable tools.

3. Formulation of the research objective

The objective of this study is to develop a method for context-aware user interface adaptation based on determining the distance to the user, which enables dynamic scaling of the typographic system to reduce cognitive load and enhance the comfort of real-time interaction.

Let d be the estimated distance from the user to the screen, and $P(d)$ be the vector of typographic parameters of the interface, which includes:

– font size;
– line spacing;
– character spacing;
– paragraph indentation.

Then the adaptation problem consists in constructing a transformation $F : d \to P(d)$, where F is an adaptation function that establishes a relationship between the estimated distance d from the user to the screen and the vector of typographic interface parameters $P(d)$.

To achieve this goal, the following tasks must be solved:

– analyze existing approaches to determining the distance to an object (user);

– develop a method for dynamically scaling the user visual interface based on a proportional relationship between the distance from the interface to the user and the size of the base typographic unit (font size), from which all related parameters (line spacing, character spacing, and paragraph indents) are calculated;

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– experimentally investigate the influence of variable factors (head tilt in the frontal and sagittal planes, rotation in the horizontal plane), as well as the chosen approach to determining the distance to the object, on the accuracy of distance measurement; analyze the obtained results.

4. Materials and methods

The mathematical basis of the proposed method is a linear scaling model, which establishes a directly proportional relationship between the physical distance to the user and the final font size (point size) of interface elements. The target font size S is calculated using the following formula:

$$S_{final} = S_{base} \times \left(L_{current} / L_{base} \right),$$

where S_{final} – the final (adapted) font size to be displayed to the user; S_{base} – the base, or reference, font size (e.g., 16pt). This is the size considered optimal for reading at the reference distance; $L_{current}$ – the current distance to the user, dynamically measured by the system (e.g., in centimeters); L_{base} – the base (reference) distance (e.g., 50 cm) for which S_{base} is calculated.

Let's introduce a scaling factor $K = L_{current} / L_{base}$ to determine how much the current distance differs from the reference distance. If $K = 1$, the user is at the reference distance, and the font remains the base size. If $K > 1$, the user is farther away than expected. The system proportionally enlarges the font to maintain readability. If $K < 1$, the user is closer. The system proportionally reduces the font size to avoid excessive visual strain and fit more information on the screen.

In addition to distance, it is important to consider the lighting in the room where the user is located in order to reduce cognitive load (Table 1).

The proposed structural-functional diagram of the method for dynamically scaling the user interface based on the estimated distance to the user is shown in Figure 3.

Table 1. *The dependence of sign legibility on distance and lighting*

Distance from the eyes	Lighting	Minimum font size (body text) mm (pt)	Font size for important text mm (pt)
Up to 50 cm	200–500 lux	2,5–3 mm (7,1–8,5 pt)	3–5 mm (8,5–14,2 pt)
Up to 50 cm	>500 lux	2–3 mm (5,7–8,5 pt)	2,5–5 mm (7,1–14,2 pt)
50–100 cm	200–500 lux	3–5 mm (8,5–14,2 pt)	5–7 mm (14,2–19,8 pt)
50–100 cm	>500 lux	2–3 mm (5,7–8,5 pt)	3–5 mm (8,5–14,2 pt)

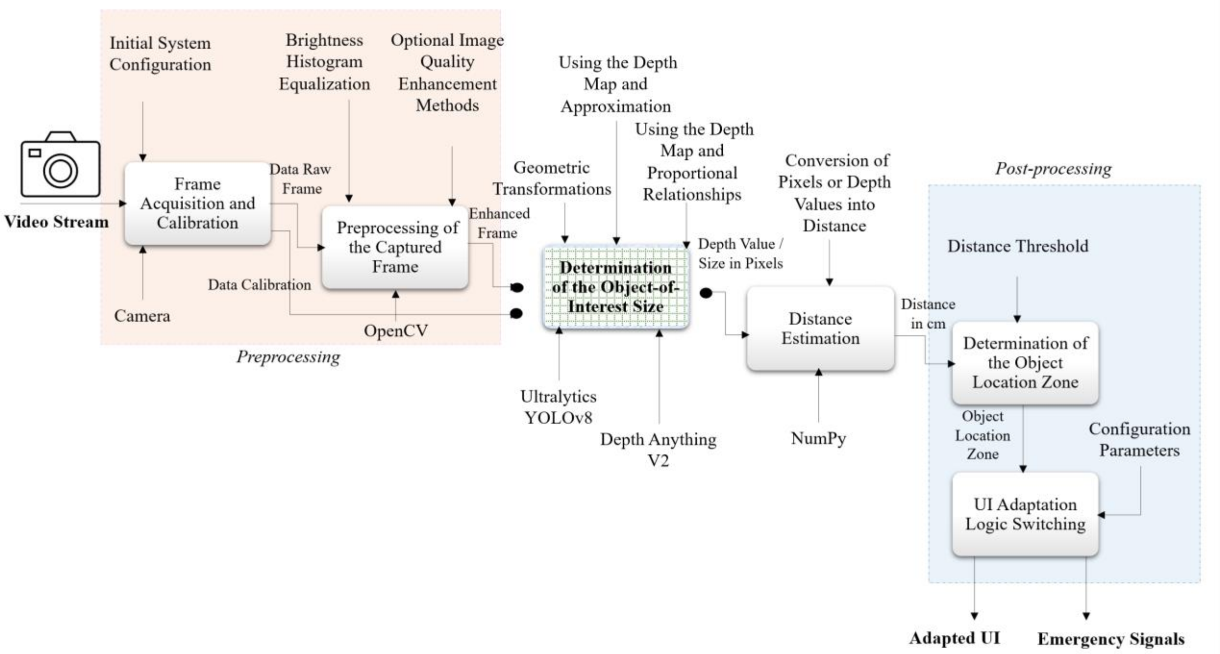

Fig. 1. Structural and functional diagram of the method for dynamically scaling a user interface based on the estimated distance to the user

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The proposed method for dynamically scaling a user interface is based on estimating the distance to the user using data from the camera's video stream.

The input data for the described method consists of video frames from the camera, the initial configuration and calibration parameters of the video recorder, and image preprocessing rules for the subsequent main stage of the method – determining the distance to the user. This stage serves as the basis for deciding on further interface adaptation.

The output is an Adaptive User Interface (Adaptive UI), in which the scale and display logic of elements change according to the estimated distance between the user and the system.

The accuracy of the interface's adaptation to the distance from the user depends most on the object-of-interest sizing module, since its result serves as the input data for the distance estimation module. Errors arising at this stage lead to incorrect determination of the user's location and selection of the interface scaling mode. Thus, the more accurately the object's size and, accordingly, the distance to the user are determined, the more correctly Adaptive UI's dynamic scaling is performed. Therefore, further research focuses on refining algorithms to compensate for the effects of head rotations and tilts, particularly by using more accurate models for estimating a person's posture.

The introduced scaling factor K characterizes the deviation of the current user distance from the reference distance. Then the adapted font size is determined as

$$S_{final} = S_{base} \times K \ .$$

Other parameters of the interface's typographic system are scaled in the same way:

$$I_{final} = I_{base} \times K,$$
$$C_{final} = C_{base} \times K,$$
$$A_{final} = A_{base} \times K,$$

where I – line spacing, C – character spacing, A – paragraph indentation; I_{base}, C_{base}, A_{base} – their default values, and I_{final}, C_{final}, A_{final} – adapted values calculated based on the current distance from the user. This approach ensures consistent scaling of the entire typographic system of the interface and preserves the visual integrity of information presentation.

This paper presents an empirical study of various existing approaches for estimating the user's distance from the user interface to assess the accuracy of these approaches [12]:

– using geometric transformations [13, 14];
– using a depth map and approximation [15];
– using a depth map without approximation [16, 17].

The algorithm for the first approach studied is described in Figure 2. The simplified geometric approach determines the distance to an object based on the relationship between its size in pixels and the actual distance to the camera. After calibration in the range of 30–120 cm, the obtained data were approximated using a quadratic polynomial, which allowed for rapid estimation of the distance in centimeters. Despite its simplicity and speed, the method has limited accuracy due to its strong dependence on the stability of shooting conditions: camera position, viewing angle, and lighting.

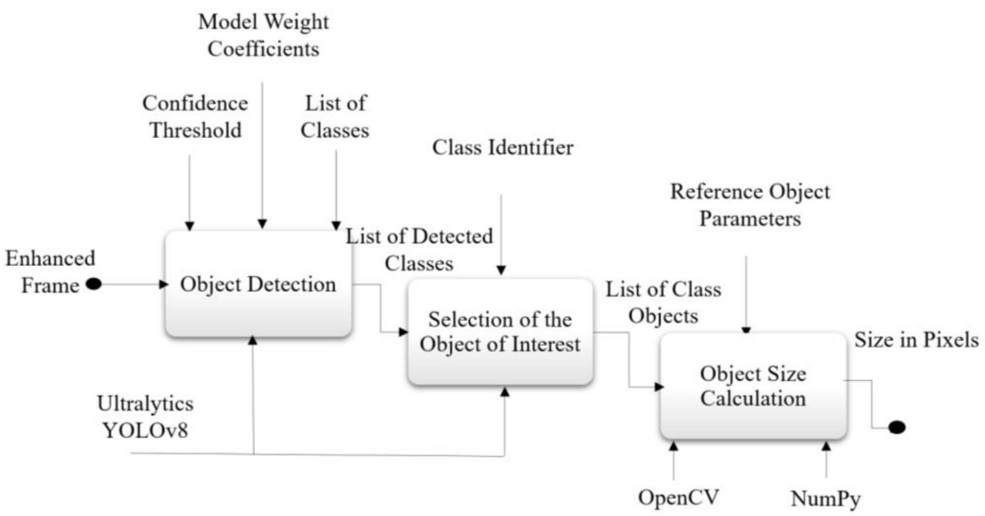

Fig. 2. Determining the size of the object of interest in the frame based on geometric transformations

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The algorithm for the second approach studied is shown in Figure 3. It is based on a combination of object detection using YOLOv8 and analysis of depth maps from the Depth Anything V2 model. Unlike the first geometric method, which estimates distance based on the object's size in pixels, this method directly measures the scene's depth.

The algorithm includes the following steps:

1. Object detection in the frame (YOLOv8).
2. Selection of the target object of interest.
3. Determining the region of interest (ROI) for it.
4. Calculating the median depth value within this region from the depth map.
5. Converting relative depth values to absolute values (centimeters) through pre-calibration. This approach is independent of the object's size in the frame and is significantly less sensitive to changes in viewing angle, which potentially improves the accuracy of distance measurement in real-world conditions.

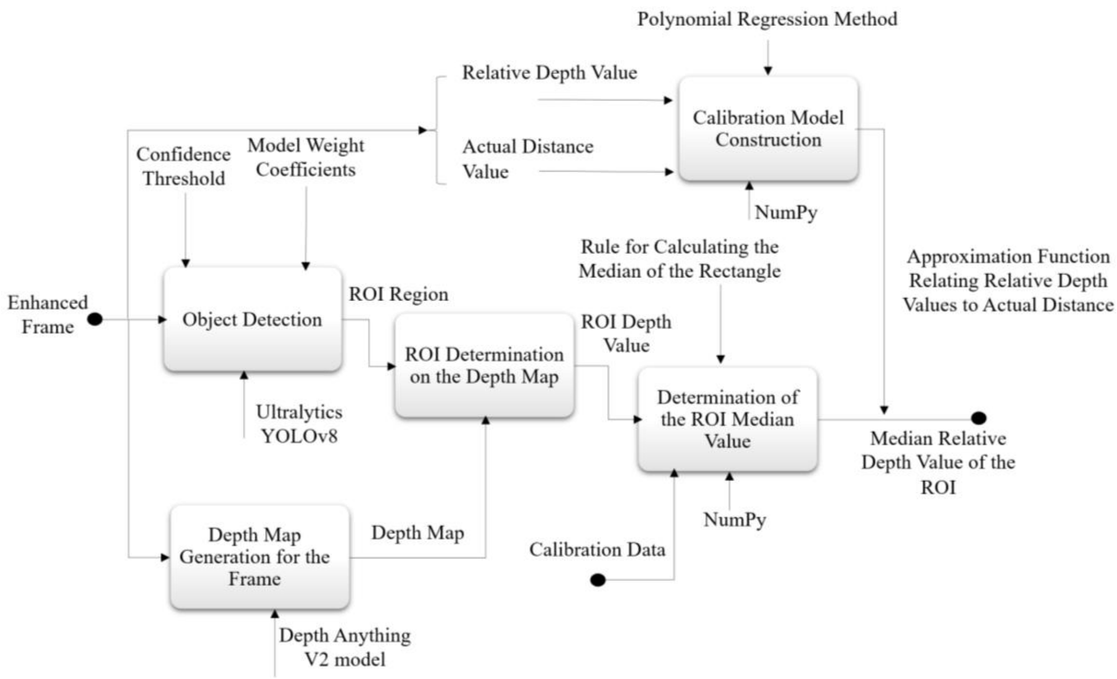

Fig. 3. Determining the size of the object of interest in the frame based on depth maps and approximations

The algorithm for the third approach studied (using a depth map without approximation) is similar to the second, as it is also based on constructing depth maps, but it includes a simplification: it omits the step of building a calibration model and does not use a function to approximate relative depth and actual distance. Instead, a reference depth is specified at a known distance.

5. Results and discussions

During the research, the influence of the user's actual distance from the screen, the lighting level in the room where the user is located, as well as the angle of head tilt in the frontal and sagittal planes was evaluated, corresponding to the real-world conditions of using the proposed and developed system. Figure 4 demonstrates the results of the studied methods, which use different approaches and therefore have different computational complexity, different execution times, and different accuracy in distance determination.

The experimental validation of the proposed approach was conducted in two stages. In the first stage, a comparison was performed between three methods for determining the distance to the user: a method using geometric transformations, a method based on a depth map with approximation, and a method based on a depth map without approximation. The comparison was performed at four reference distances: 30, 60, 90, and 120 cm, corresponding to 12 controlled experimental configurations. In the second stage, for the method selected for further analysis, the effect of the user's head position was investigated: in the frontal plane, in the sagittal plane, and during rotation in the horizontal plane. For each type of orientation, the evaluation was

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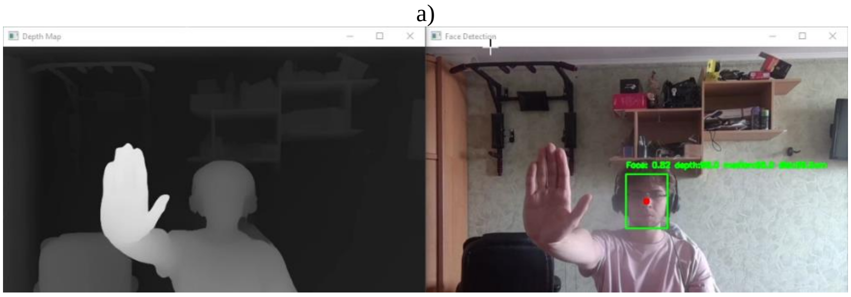
performed at three angles of deviation and four reference distances, resulting in an additional 36 configurations. Thus, the overall error assessment presented in this work is based on 48 controlled experimental configurations.

The first experiment focuses on determining the approach that yields the smallest error when measuring the user's distance from the screen. The experimental results are presented in Table 2.

a)



b)

Fig. 4. Visual demonstration of the experimental results:
a) display of the calculated distance at 30 and 40 cm using the geometric transformation method;
b) display of the calculated distance at 120 cm using the method based on a depth map and approximation

Table 2. *Error estimation for determining the user's distance from the screen depending on the selected approach and the actual distance from the screen*

Method \ Distance	Real distance from the screen, cm			
	30	60	90	120
Method using geometric transformations	2%	0.33%	0.56%	8.92%
Method based on a depth map and approximation	3.67%	1.83%	2.11%	17.08%
Method based on a depth map without approximation	1.33%	1.83 %	13.67%	51.25%

Table 2 presents the results of an experimental evaluation of the error in determining the user's distance from the screen for three approaches: a method using geometric transformations, a method based on a depth map with approximation, and a method based on a depth map without approximation. The comparison was performed for four reference distances – 30, 60, 90, and 120 cm. The table shows the percentage error values for each approach at each of the specified distances, allowing the results of the first stage of experimental verification to be presented in a comparative format.

The aim of the next experiment is to assess the effect of head tilt in the frontal plane at various angles (0°, 15°, 45°), head tilt in the sagittal plane at various angles (0°, 15°, 30°), as well as head rotation in the horizontal plane at angles (0°, 15°, 30°) on the accuracy of determining the distance to the screen (Figure 5). The results of the second experiment are presented in Table 3.

Table 3 presents the results of an experimental assessment of the error in determining the user's distance from the screen depending on the position of the head in space. The table shows the error values for three head orientation scenarios: tilt in the frontal plane, tilt in the sagittal plane, and rotation in the horizontal plane. For each option, several angles of deviation were considered, and the evaluation was performed at four reference distances – 30, 60, 90, and 120 cm. The percentage error values presented in the table allow for a general overview of the results of the second stage of the experimental study for various spatial positions of the user's head.

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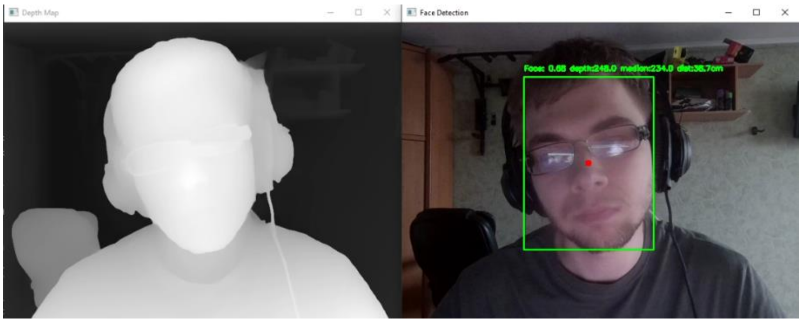
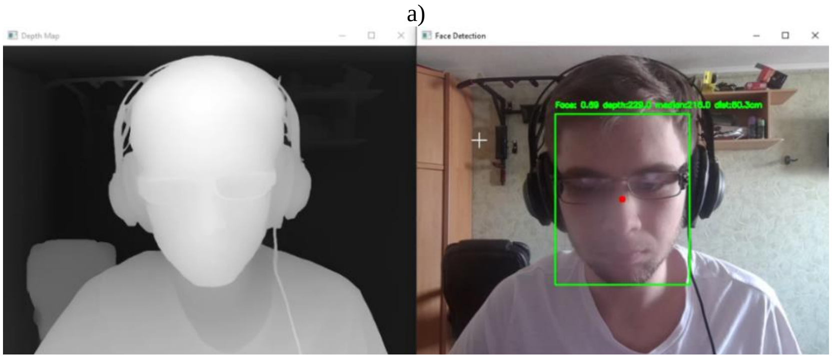


a)



b)

Fig. 5. Visual demonstration of the results of the experiments:
a) distance measurement at 30 cm with the head tilted 15o in the frontal plane;
b) distance measurement with the head tilted 15o in the sagittal plane

Table 3. *Estimation of the error in determining the user's distance from the screen depending on head position in space and actual distance from the screen, %*

Plane	Angle	30 cm	60 cm	90 cm	120 cm
Frontal plane, tilt	0°	25.3 %	10.7 %	3.6 %	1.1 %
	15°	19.0 %	20.0 %	10.8 %	4.9 %
	45°	40.0 %	8.8 %	2.8 %	2.3 %
Sagittal plane, tilt	0°	1.67 %	7.0 %	4.0 %	3.3 %
	15°	100.7 %	18.7 %	33.1 %	31.2 %
	30°	137.0 %	2.3 %	47.7 %	13.1 %
Rotation in the horizontal plane	0°	7.3 %	3.2 %	4.0 %	0.4 %
	15°	201.3 %	89.2 %	21.0 %	4.5 %
	30°	127.7 %	62.2 %	26.0 %	10.7 %

6. Discussion of Results

Analysis of the results of the first experiment (Table 2) demonstrates that for short and medium distances, all three approaches provide satisfactory accuracy. However, as the distance increases, the use of geometric transformations demonstrates the highest stability. A drawback of this approach is that it can only determine the distance for specific objects, for which the system was previously calibrated. Changing the focal length also reduces the reliability of this approach, as it requires a complete recalibration of the system. The third approach exhibits the highest error values. The second approach does not require a complete recalibration of the system when the user changes, so it is recommended for subsequent experiments.

Analysis of the results (Table 3) showed a clear dependence of distance measurement accuracy on the user's head position. The most critical factor was a distance of 30 cm, where extreme error values were recorded – up to 201.3% with a 15° head rotation and 137.0% with a 30° sagittal tilt. Head rotations in the horizontal plane consistently produce the highest errors among all types of movements.

The lowest error values are generally observed at zero head angles compared with non-zero tilt and rotation conditions. At the same time, the results are not uniformly stable across all distances: for example, in the frontal plane at 30 cm the error reaches 25.3%, while at 60–120 cm it decreases to 10.7%, 3.6%, and 1.1%, respectively. There is also a noticeable positive trend of decreasing error with increasing distance – at 120 cm, accuracy improves significantly even at significant angles of deviation.

Based on the results presented in Table 2 and Table 3, the second research objective, which was to determine the effect of the user's head position on distance measurement accuracy, was experimentally resolved.

The results obtained indicate the need for additional correction of measurement algorithms, especially for close distances, through the implementation of compensation mechanisms that account for the orientation of the head in space.

The developed methods and results of the experiments have the potential to be used in the creation of adaptive visual interfaces for information systems of various purposes, including educational platforms, medical services, banking and administrative terminals, mobile and desktop applications, as well as digital services for users with visual impairments. The development holds particular value for industry, as it can be integrated into HMI solutions, operator panels, smart displays, and systems for monitoring and controlling production processes, where readability, speed of information perception, and reduction of cognitive load on the operator are critical. In this context, the method can be viewed as a tool for improving the ergonomics, accessibility, and reliability of digital interaction in modern industrial and service environments.

7. Conclusions

During the course of this study, a method for context-aware interface adaptation was developed, the main functional element of which is determining the distance to the user, based on which the font size and related typographic parameters of the visual user interface (line spacing, character spacing, and paragraph indentation) are dynamically adjusted.

It has been experimentally proven that the approach based on depth maps and approximation (YOLOv8 + Depth Anything V2) is the most balanced solution. It combines acceptable accuracy (an error of 1.83–3.67% at distances of 30–90 cm) with resistance to changes in shooting conditions and the absence of the need for complete recalibration of the system when the user changes, unlike the geometric method.

A critical influence of the user's head orientation on measurement accuracy was identified. The largest errors (up to 201.3%) were recorded at close range (30 cm) when the head was rotated in the horizontal plane. This indicates the need to integrate compensation mechanisms that account for the user's posture in real time.

The scientific novelty lies in the development of a method for context-aware adaptation of a visual user interface, in which the estimation of the distance to the user is used as a contextual trigger for dynamically scaling not only the font size but also related typographic parameters, as well as in establishing the influence of the user's head orientation on the accuracy of distance measurement.

The practical significance lies in the possibility of applying the proposed method during the development of adaptive visual interfaces that automatically adjust display parameters depending on the distance to the user and can be used to improve readability, ease of information perception, and the accessibility of digital services.

Further research will focus on refining algorithms to compensate for the effects of head rotations and tilts, particularly by using more accurate models for estimating a person's posture. The integration of additional contextual factors, such as more accurate determination of ambient light levels and their automatic incorporation into the scaling model in the future, will also ensure greater system resilience to changing conditions.

Conflict of interest

The author declares that there is no conflict of interest, particularly of a financial, personal, authorial, or any other nature, that could influence the research or the results published in this article.

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Data availability

The manuscript contains data in the form of electronic supplementary material.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies to write this work.

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МЕТОД КОНТЕКСТНО-ОБІЗНАНОЇ АДАПТАЦІЇ ВІЗУАЛЬНОГО КОРИСТУВАЦЬКОГО ІНТЕРФЕЙСУ НА ОСНОВІ ОЦІНКИ ВІДСТАНІ ДО КОРИСТУВАЧА

Актуальність теми дослідження зумовлена необхідністю переходу від статичних інтерфейсів до гнучких систем, здатних динамічно адаптуватися до фізичного контексту користувача, зокрема до зміни відстані від екрана, що дозволяє знизити когнітивне навантаження та підвищити комфорт взаємодії. **Об'єктом дослідження є** процес контекстно-обізнаної адаптації користувацького візуального інтерфейсу в реальному часі залежно від відстані до користувача, а саме – типографічних параметрів користувацького інтерфейсу. **Предметом дослідження є** підходи до визначення відстані до користувача на основі даних відеопотоку**.** **Метою дослідження** є розробка методу контекстно-обізнаної адаптації користувацького інтерфейсу на основі визначення відстані до користувача, що забезпечує динамічне масштабування типографічної системи для зниження когнітивного навантаження та підвищення комфорту взаємодії в реальному часі**.**. Для досягнення поставленої мети було вирішено такі **завдання**: проаналізовано існуючі підходи до визначення відстані до об'єкта, розроблено метод динамічної зміни масштабу користувацького візульного інтерфейсу, що ґрунтується на пропорційній залежності між відстанню інтерфейсу до користувача та розмірами базової типографічної одиниці (кеглю). Для експериментального підтвердження високої точності визначення відстані від візуального інтерфейсу до користувача було досліджено вплив варіативних факторів (нахил голови у фронтальній та сагітальній площинах, поворот в горизонтальній площині), а також обраного підходу до визначення відстані до об'єкта на точність вимірювання відстані. **Розроблений метод** забезпечує адаптацію не лише розміру шрифту, а й пов'язаних із ним типографічних параметрів (міжрядковий та міжлітерний інтервали, абзацні відступи). **Встановлено**, що підхід на основі глибинної карти з апроксимацією забезпечує найбільш збалансовані результати за точністю та практичною придатністю, демонструючи похибку 1.83–3.67% у діапазоні 30–90 см. Також показано, що орієнтація голови користувача є критичним фактором впливу на точність вимірювання, а максимальна похибка на близькій дистанції сягає 201.3%.

Ключові слова: інтерфейс; відстань; комп'ютерний зір; карта глибини; модель; метод.

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