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Olesia Barkovska
PhD of Computer Science, Associate professor, Department of Electronic Computers
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID ID 0000-0001-7496-4353
olesia.barkovska@nure.ua

Yaroslav Liapin
Master's student of Department of Electronic Computers
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID ID 0009-0008-9881-733X
yaroslav.liapin@nure.ua

Tetiana Muzyka
PhD of Law Sciences,
Lecturer Assistant of the Department of Civil Law Politic, Intellectual Property Law and Innovations
Yaroslav Mudryi National Law University, Kharkiv, Ukraine
ORCID ID 0000-0001-5267-0987
t.o.muzyka@nlu.edu.ua

Ihor Ryndyk
Master's student of Department of Electronic Computers
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID ID 0009-0005-8278-3516
ihor.ryndyk@nure.ua

Pavlo Botnar
Master's student of Department of Electronic Computers
Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
ORCID ID 0009-0008-7218-9515
pavlo.botnar@nure.ua

GAZE DIRECTION MONITORING MODEL IN COMPUTER SYSTEM FOR ACADEMIC PERFORMANCE ASSESSMENT

Abstract. This paper focuses on the research and application of eye movement and gaze direction analysis in online testing systems. The practical novelty of the proposed model of monitoring the direction of gaze in a computer-based knowledge control system lies in the possibility of automated remote control over a large audience of students. The practical significance lies in creating the same conditions for computer testing for all students and increasing the correspondence of knowledge level to the received test results. The implemented and tested system is relevant and necessary in higher educational institutions, particularly in Ukraine, where remote education has emerged as the safest means of acquiring knowledge. This is especially true for fields of study where practical tasks and laboratory work do not necessitate a student's physical presence at the institution. That is why the application of the latest information technologies is extremely important. The dynamic authentication based on the sequence of eye movements proposed in the model allows error-free user's eye area detection for further analysis of the test subject's behavior. The proposed authentication method excludes the need to enter passwords or CAPTCHAs, ensures the speed of determining the user's presence.-Further analysis of the user's direction of vision includes responding to the information received, such as skipping a question or the need for re-authorization. Question skipping occurs when the system decides that the user has not been looking at the screen for an extended period (looking sideways, down, up for more than 30 seconds). Re-authentication becomes necessary if the user exits the test or if there is a user replacement. Real-time gaze control capability is implemented by using massive parallel processing system (NVIDIA GeForce GTX 1650 graphics card) for calculations. The analysis of the results obtained shows that the proposed approach allows gaze detection at different illumination ranges (from 0.3 lux to 10,000 lux), as well as to detect states of the user's eyes that violating test rules for further system response (skipping a question or re-authentication request).

Keywords: remote education; testing; credibility; academic performance assessment; gaze; contract on the provision of educational services.

1. INTRODUCTION

The problem statement. For years, Ukraine has been paying a lot of attention to the development of distance education. For schoolchildren and students from the temporarily occupied territories, frontline territories and areas of active hostilities, e-learning is the most effective tool for ensuring access to education. In response to the full-scale invasion of the Russian Federation into Ukraine and the introduction of the legal regime of martial law, the Law of Ukraine "On Education" was amended. Specifically, Article 57-1 was added to establish state guarantees during the period of martial law. One of such guarantees is the organization of educational process in a remote form or in any other form that is the safest for its participants [1]. However, the active stage of transition began on 12 March 2020, when, according to a resolution of the Cabinet of Ministers of Ukraine, education in all educational institutions of Ukraine was transferred to a distance format because of COVID-19 pandemic.

There are many definitions of remote education:

– firstly, remote education is an individualized process of education, which takes place mainly via indirect interaction of participants of remote educational process in a specialized environment, which operates on the basis of modern psychological, pedagogical and information and communication technologies [2];
– secondly it is organized self-education carried out within educational institution, and confirming the acquired qualification with the relevant document;
– thirdly, and most meaningfully, in our view, it is a synthetic, integral, humanistic form of education based on the use of a variety of traditional and new information technologies and their technical means used to deliver educational material, its independent studying, and organization of a dialogical exchange between teacher and students, when learning process is not limited in space and time and does not involve the constant, mandatory presence of students in a particular educational institution [3].

Characteristic features of distance learning include the following: it is based on information technology, basis of distance education is software and methodological support, lack of unified standards for technical support and user identity verification [4], [5], [6].

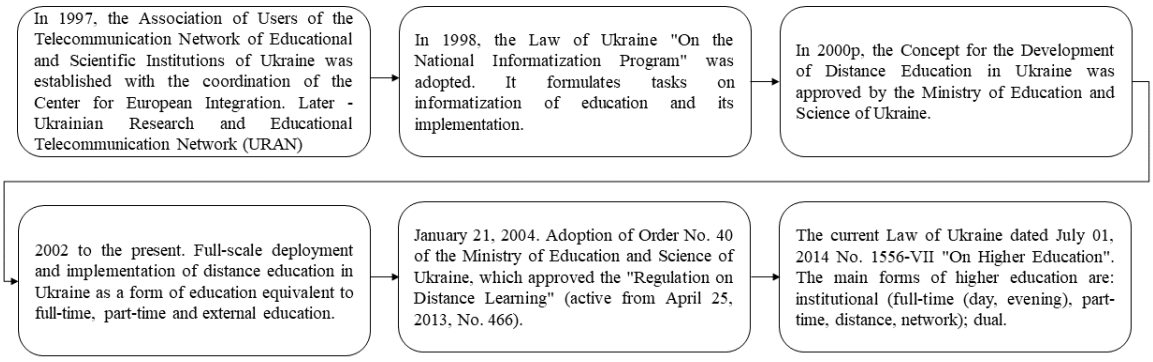


Figure 1. Chronology of the distance education in Ukraine development

Previously, the development of modern information technologies drove the improvement of the education system. However, in today's context, the widespread adoption of distance

education in most of Ukraine necessitates ongoing enhancements and modernization of information technologies [7], [8].

The chronology of the development of remote education in Ukraine is illustrated-in Figure 1. The history of distance learning in Ukraine commenced over twenty years ago. Current challenges faced by the Ukrainian education system require the creation of an education system that will ensure the transition to "lifelong education", while maintaining openness of learning and active communication between a teacher and a student through modern information, communication and multimedia technologies [9].

The implementation of remote education in Ukraine is regulated by a number of regulatiry instruments, namely "The National Doctrine of Education Development", "The Concept for the Development of Remote Education in Ukraine", "On the National Informatization Program", the Laws of Ukraine "On Education" and "On Higher Education", and the Order of the Ministry of Education and Science of Ukraine "On Approval of the Regulation on Remote Education". Currently, the Department of Higher Education of the Ministry of Education and Science of Ukraine, the Ukrainian Institute for Information Technologies in Education, and university departments are responsible for organising and implementing remote education in Ukraine.

The forced transition to remote education, spanning over four years, has compelled educators to adapt to new realities and address the challenges that arose at the beginning of the pandemic. Presently, remote education should be viewed as a distinct form of education rather than a temporary alternative to full-time education. As such, it necessitates ongoing improvement, updates, and cyclical development of all components within the virtual informational and educational environment. This makes the topic of this paper relevant and in high demand.

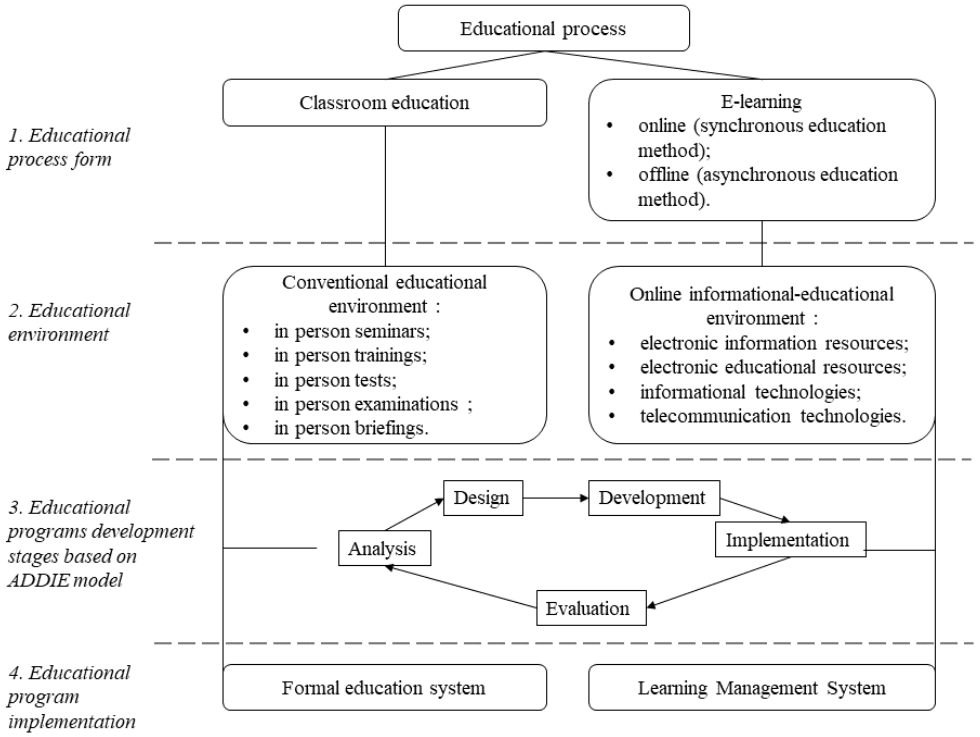


Figure 2. Organization of different educational process forms

Analysis of recent research and publications. A detailed analysis of the research area was conducted based on the following criteria: the educational environment, the stages of educational curriculum development, and their dependence on the form of the educational

process, as well as the ways of implementing educational programs. The analysis in Figure 2 shows that any form of education involves general stages of curriculum development, which are, in their turn, cyclical (ADDIE step-by-step curriculum design model [10], [11]: Analysis; Design; Development; Implementation; Evaluation. All steps of ADDIE model are interconnected. Each stage generates results that form a basis for the next stage.

Implementation of the steps of curriculum development in remote education is achieved through the use of learning management systems (LMS).In addition to setting goals and objectives of education, selecting and sequencing teaching methods (Figure 3), another important step is to assess learning activities, which is carried out following these principles [12]:

- planning;
- systematicity and consistency;
- objectivity;
- openness and transparency;
- cost-effectiveness;
- thematic (modularity) principle;
- taking individual capabilities of students into account;
- unity of demands.

Knowledge check is the final stage of the educational process. The efficiency of management of educational process and quality of specialist training largely depend on its correct organisation [13].

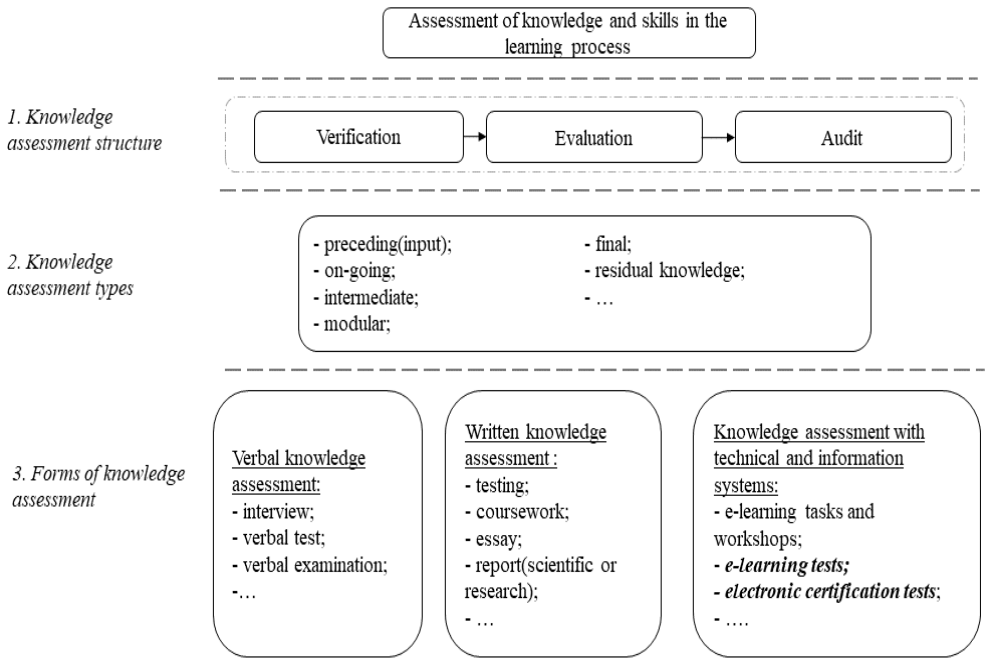


Figure 3. Assess knowledge and skills as the final stage of any form of educational process

The main requirement for the academic performance assessment system is to ensure the quality and reliability of information to make correct and effective decisions on learning process management. The goal can be achieved by improving the most common form of academic validity:

- efficiency;
- objectivity

- reliability;
- and psychological and ethical aspects of the academic performance assessment system.

performance assessment in LMS is test-based control, which is the focus of the research in this paper. Some of the existing solutions that have been implemented in the educational process include Examus, Exam Cookies, Exam Monitor, Proctortrack, Black Board, ILIAS, Desire2Learn, RedClass, eLearningServer, MOODLE, Assistant II, eTest, MyTest X, VeralTest, SunRav TestOfficePro, and others.

Reviewed knowledge testing systems differ in the following aspects:

- rights distribution – administrator and user modes existence;
- an option to make tests in the application;
- option of uploading tests that have been prepared in advance according to a certain template to application;
- test editing capabilities for tests that have already been created or uploaded;
- evaluation and recording of the results for all users who have passed the test;
- user access management in database by administrator;
- moving between questions or returning to the previous ones;
- time limit for the test, which can be configured;
- message sending to a specific student;
- additional opportunities to increase validity and reliability, such as: monitoring user's clipboard; tracking active user processes; taking screenshots of the working area of the computer screen; taking shots from a web camera; obtaining the active URL in different browsers; obtaining a list of pressed keyboard keys; getting a list of network connections and processes; the use of a web camera for continuous monitoring; real-time tracking of the testing process; etc.

The given broad functionality of the existing remote computer knowledge testing systems is not able to limit the use of third-party auxiliary materials by students, and therefore is not able to ensure the reliability of knowledge assessment.

Gaze tracking is widely used in various fields (Table 1) [14], [15],[16] so in this paper, it has been proposed to apply it in pedagogical activities to increase the reliability of remote computer knowledge testing systems. The proposed solution does not course discomfort for the tested person and does not extend the test time. This underscores the practical novelty and significance of the proposed solution.

Table 1

Fields of use for gaze tracking methods

Field of use	Accomplished tasks
Clinical and medical research	gaze movement analysis helps in diagnosing autism, studying perceptual and cognitive development, ADHD, eye diseases, and others. It is also used in communication systems for completely paralysed people
Education, reading and language research	gaze monitoring is a tool for objectively measure human language processing
Management of engineering developments	in the management of complex systems, for example, in aviation, eye tracking allows you to monitor the gaze, improving human-machine interaction
Marketing and consumer research	gaze monitoring helps to obtain cognitive data by monitoring the respondent's gaze. It is one of the most reliable methods in understanding how customers view and respond to advertising messages in retail and media channels. An example of its application is the study of web content usability

Solutions to the tasks listed in the table are usually complex and can be decomposed into the following sub-tasks [17], [18]: determination of gaze direction; monitoring of the duration of gaze fixation, both fast and smooth eye movements between fixations, gaze and maximum

eye movement speed; analysing eyelid movements through observation of how wide eyes are opened, how often a person blinks and how long their eyes remain closed; analysing eyeball state, for example, redness, degree of pupil dilation/contraction (which is known to be an indicator of excitement); etc. [19], [20].

The weaknesses of remote testing include:

- cheating. This phenomenon greatly reduces the objectivity of knowledge assessment, so one of the proposed solutions can be considered blocking educational material during testing, but this will not solve the problem, since the resources of the World Wide Web are much wider than textbooks. That is, this problem does not yet have a solution;
- being tested by another person. Access to the curriculum is provided using individual passwords. Separately, you can connect a proctoring system, when what is happening on the monitor is monitored by an administrator or teacher using a webcam, but this approach limits the number of students taking testing at the same time. That is, this problem does not yet have a solution;
- falsification of results. Modern platforms use statistical protection during testing and special algorithms that help identify fraud;
- selecting answer options at random. You can make and add active test formats: finish a thought or write the answer on a blank line;
- transferring the correct answers to those who have not yet taken the test. This problem can be controlled by changing the order of questions.

The research goal. The goal of this paper is to improve the reliability of students' knowledge assessment when using remote system for academic performance assessment. This is achieved by monitoring and evaluating the student's gaze direction, thereby ensuring the absence of the use of additional external materials, literature, and electronic gadgets.

In order to reach this goal, the following objectives should be fulfilled:

- justification of relevance and demand for improvement of reliability of remote system for academic performance assessment;
- analysis of existing knowledge control systems to identify their functional capabilities and limitations;
- development of a generic computer-based knowledge testing model with enhanced assessment reliability through monitoring the gaze direction;
- implementation of users' gaze monitoring fununction;
- results analysis.

This paper proposes an approach to improve the reliability of knowledge assessment through the use of web cameras for continuous monitoring and analysis of the test subject's gaze direction, provides qualitative characteristics of the testing results of proposed approach, and justifies the psychological and ethical comfort and legal aspects of testing with the proposed extension.

2. THE RESULTS AND DISCUSSION

As certain forms of learning and knowledge control can either help students show valid learning results by stimulating their academic integrity, or hinder academic integrity, especially where the higher educational establishment and its scientific and pedagogical stuff neglect the latest technologies of control, and since the quality control of the acquired knowledge and the form of its implementation are important parts of the contract for the provision of educational services in higher educational establishments, it’s vital to acknowledge that improving and expanding the functionality of existing learning management systems is an urgent and in-

demand task.

Our project was implemented using Python because of the wide range of standard libraries and frameworks and large community of developers, which means that additional packages and libraries are constantly being developed and features are being extended [21], [22]. A summary model for gaze direction monitoring in a computer cystem for academic performance assessment is shown in Figure 4.

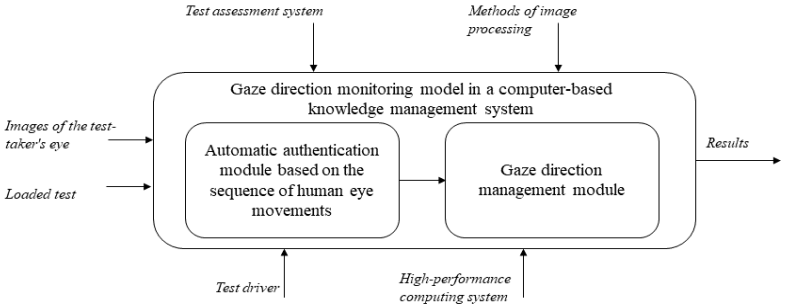


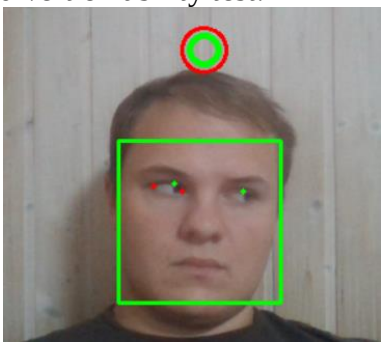
Figure 4. Gaze direction monitoring model in computer system for academic performance assessment

The following libraries were used in the development:

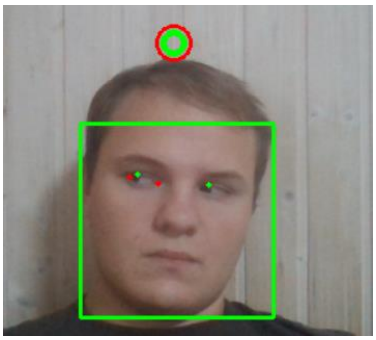
– Tkinter – library, that includes operations with windows, their elements, and layouts. In a project, this library provides structure of the user interface [23];
– openCV – library for images processing, received from camera;
– dlib – library for face and its elements detection;
– Pillow – library for converting images into a format for use with Tkinter;
– Math – library for carrying out calculations;
– Time – library that contains functions which are used to work with time;
– Threading – a library for working with threads. In the project, this library is needed to simultaneously run both the interface and camera data collection.
– numpy – library for array processing [24].

The first step of the model is to determine whether a human user is available for testing at the moment. In order to determine this, we propose to use dynamic authentication based on a series of eye movements (Figures 5-6). To do so, the user is required to perform a series of eye movements in accordance with the commands displayed on the screen of a computer or mobile device, for example:

– blink ability test;
– gaze focus ability test;
– gaze divertion ability test.



a)



b)

Figure 5. Authentication: a) reaction to the command "look to the left"; b) reaction to the command "look to the right"

The advantage of this authentication method is the absence of need of passwords or CAPTCHAs, the speed of user presence detection, and the error-free location of user's eye area for further analysis of tested's behaviour.

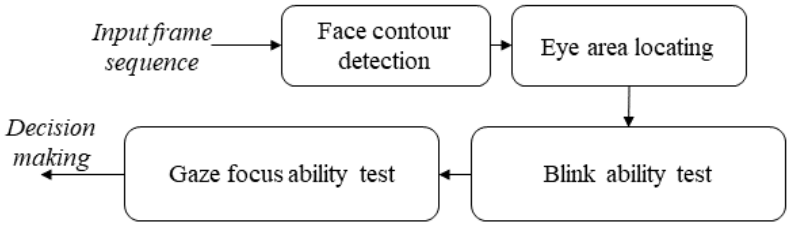


Figure 6. Human eye movements analysis (authentication process)

After confirmation that a tested person is a human and locating the area of interest – the eye area – management is delegated to the gaze direction monitoring module.

The formal algorithm of the application is illustrated in Figure 7.

The images are processed frame by frame in real time. Each image is converted into a two-dimensional array, providing information about the direction of view and the user's face.

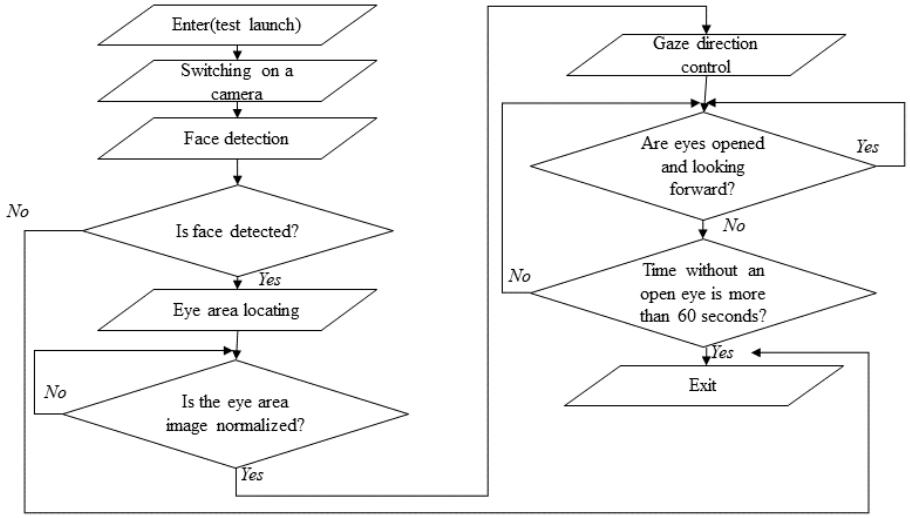


Figure 7. Application algorithm

The ability to detect faces and locate the eye area was tested and found to work correctly in different illumination ranges from 0.3 lux to 10,000 lux (Figure 8).

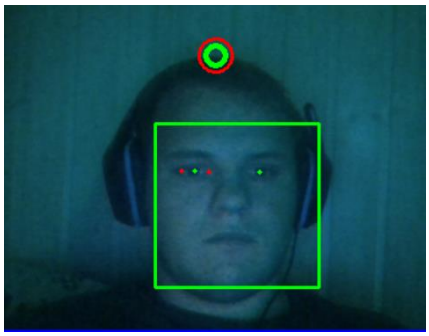


Figure 8. Application result at 1 lux illumination

The second step (gaze direction monitoring module) of the proposed model of gaze direction monitoring in computer system for academic performance assessment is time-consuming and must operate in real time, so all further eye condition processing was transferred to a massively parallel processing system(GPU). The system's response to the "openness" of the eye is demonstrated by an increase and decrease of the circle above the user in Fig. 9.

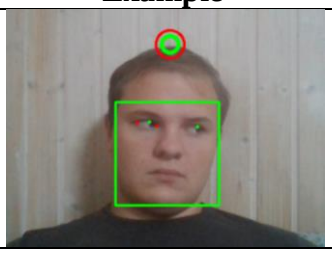
Figure 9. Evaluation of eye openness

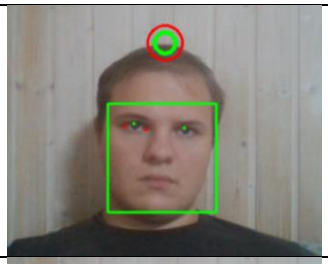
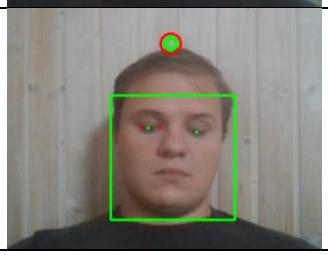
Analysis of the user's gaze direction involves a response to the information received, such as skipping a question or re-authorisation demand. Question skipping occurs when system decides that user is not looking at the screen for a long time (Table 2). Re-authentication is required if the user has moved away from the screen or if the user has been replaced.

Eye conditions that are considered to be violations of behavioural norms during the test are shown in Table 2. If one of the above states is detected by the system and lasts for more than 30 seconds, the system automatically moves on to the next question, concluding that the current one is not known.

Table 2

Unacceptable gaze states of the user during testing

State explanation	Example
Long sideways stare (longer than 30 seconds)	

Long stare over the camera (longer than 30 seconds)	
Long stare down (longer than 30 seconds)	

For the further development of the proposed model, it is planned to rely on the Concept of the development of artificial intelligence in Ukraine [25], that defines the implementation of informational technologies, including artificial intelligence technologies, as an integral component of development of social and economic, scientific and technical, defense, legal and other activities in the spheres of statewide significance. Actually, education is also a sphere of statewide significance. Considering this, it can be confidently emphasized that the usage of artificial intelligence technologies contributes to a significant improvement in the quality of the educational process, in particular for knowledge control, where the tasks of authorization and authentication can be solved by artificial intelligence methods. Such innovations will contribute to the fact that the student (cadet) will be more focused on the task, realizing that s/he will not be able to resort to dishonest methods of passing control, which increases the level of reliability of the results obtained.

Contribution to the scientific research presented in the article. To implement the tasks, theoretical methods of scientific and pedagogical research were used (studying the literature on the research topic; studying and summarizing the pedagogical experience of training and evaluating the knowledge of bachelor's and master's students who study in the distance form of education; modeling) as well as mathematical (methods and algorithms of digital image processing – image normalization, noise deletion, area of interest detection).

Contribution of the authors to the article: the idea of writing the article, development of the research methodology, analysis of the obtained results – O. Barkovska, development of methods for detecting the area of interest (eyes), gaze direction and eyes state, translation in English – Ya. Liapin, analysis of the model proposed in the article control of knowledge during distance learning from the point of view of the educational process, as the process of providing an educational service, literature design, manuscript correction – T. Muzyka, development of the image pre-processing pipeline, graphic design of the article – I. Ryndyk, selection of theoretical material for the content of the article, analysis of available works on the topic – P. Botnar.

3. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

This paper results in the model for gaze direction monitoring in computer system for academic performance assessment. Testing of the model provides improvement of accuracy of students' knowledge assessment by analysing gaze direction of the examinee, which in turn ensures the impossibility of using additional, third-party materials, literature, or electronic gadgets.

The practical novelty of the proposed model of monitoring the direction of gaze in a computer-based knowledge control system lies in the possibility of automated remote control over a large audience of students. The practical significance lies in creating the same conditions

for computer testing for all students and increasing the correspondence of knowledge level to the received test results.

The research problem is actual and in demand among universities, and in particular in Ukraine, since classroom education is not currently possible due to the full-scale invasion of Ukraine by Russian Federation. Extended analysis of the research area has shown that any form of education includes common stages of educational program development, among which assessment of students' knowledge is mandatory and essential. The contract for the provision of educational services in higher educational establishments generally possesses a dispositive legal nature, although it also incorporates imperative elements, such as the quality control of study results. At the same time, we consider it to be the duty of higher educational establishment to provide students with the proper conditions for passing current and final control, as well as certification. In the conditions of remote learning and in accordance with the requirements of the digitalization of education, the usage of specialized software for the assessment of knowledge is organically gaining in demand, which do not require additional efforts from the students but allow them to focus on the performance of control tasks.

This model consists of two modules: a module that provides automatic authentication based on the eye movement and a module for gaze direction monitoring. The first module involves determining whether a human user is currently ready to take the test. To do this, we use dynamic authentication based on a series of eye movements that follow commands given on the monitor screen. The advantage of this authentication method is the absence of need of passwords or CAPTCHAs, the speed of user presence detection, and the error-free location of user's eye area for further analysis of tested's behaviour. Analysis of the user's gaze direction involves a response to the information received, such as skipping a question or re-authentication demand. Question skipping occurs when system decides that user is not looking at the screen for a long time (looking sideways, down, up for more than 30 seconds).

The analysis of the results demonstrates the capability to detect the gaze at various illumination ranges (from 0.3 lux to 10,000 lux) and identify specific states of the user's eyes (sideways stare longer than 30 seconds, upward stare lasting longer than 30 seconds, downward stare lasting longer than 30 seconds). These states can be indicative of violations of test rules, prompting the system to respond accordingly, such as skipping a question or initiating a re-authentication request.

The next possible steps in the model's development include the research and implementation of methods for accelerated high-precision user authentication using face recognition with gaze-based password input.

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МОДЕЛЬ МОНІТОРИНГУ НАПРЯМКУ ПОГЛЯДУ В СИСТЕМІ КОМП'ЮТЕРНОГО КОНТРОЛЮ ЗНАНЬ

Олеся Барковська
кандидат технічних наук, доцент, кафедра електронних обчислювальних машин
Харківський національний університет радіоелектроніки, м. Харків, Україна
ORCID ID 0000-0001-7496-4353
olesia.barkovska@nure.ua

Ярослав Ляпін
магістрант кафедри електронних обчислювальних машин
Харківський національний університет радіоелектроніки, м. Харків, Україна
ORCID ID 0009-0008-9881-733X
yaroslav.liapin@nure.ua

Тетяна Музика
кандидат юридичних наук,
асистентка кафедри цивільно-правової політики, права інтелектуальної власності та інновацій
Національний юридичний університет імені Ярослава Мудрого, м. Харків, Україна
ORCID ID 0000-0001-5267-0987
t.o.muzyka@nlu.edu.ua

Ігор Риндик
магістрант кафедри електронних обчислювальних машин
Харківський національний університет радіоелектроніки, м. Харків, Україна
ORCID ID 0009-0005-8278-3516
ihor.ryndyk@nure.ua

Павло Ботнар
магістрант кафедри електронних обчислювальних машин
Харківський національний університет радіоелектроніки, м. Харків, Україна
ORCID ID 0009-0008-7218-9515
pavlo.botnar@nure.ua

Анотація. Роботу присвячено інтеграції досліджень та використання аналізу руху очей та напрямку погляду в системах онлайн-тестування знань студентів. Практична новизна запропонованої моделі моніторингу напрямку погляду в комп'ютерній системі контролю знань полягає в можливості автоматизованого віддаленого контролю над великою аудиторією студентів. Практична значущість полягає у створенні однакових умов проходження комп'ютерного тестування для всіх студентів та підвищення відповідності рівня знань отриманим результатам тестування. Реалізована та протестована система є актуальною та затребуваною у вищих навчальних закладах, особливо в Україні, де дистанційна освіта перетворилась на найбільш безпечний спосіб здобуття освіти, особливо для тих сфер, де немає необхідності проводити практичні заняття, лабораторні роботи, які вимагають перебування студента в ЗВО. Тому застосування новітніх інформаційних технологій навчання набуває особливого значення. Запропонована в моделі моніторингу динамічна аутентифікація на основі послідовності рухів очей дозволяє безпомилково детектувати область очей користувача для подальшого аналізу поведінки випробуваного. Запропонований спосіб аутентифікації не передбачає введення паролів або CAPTCHA, забезпечує швидкість визначення присутності користувача. Подальший аналіз напрямку погляду користувача передбачає реагування на отриману інформацію, а саме – пропуск питання або необхідність повторної авторизації. Пропуск питання виникає тоді, коли система вирішує, що користувач довго не дивиться на екран (погляд вбік, вниз, вгору понад 30сек). Повторна автентифікація вимагається у випадку, якщо користувач відійшов від екрана або відбулась заміна користувача. Підтримка можливості контролю погляду в режимі реального часу здійснюється завдяки перенесенню обчислень на систему з масовим паралелізмом (графічна карта NVIDIA GeForce GTX 1650). Аналіз отриманих результатів показує, що запропонований підхід дозволяє детектувати погляд при різних діапазонах освітленості (від 0,3 лк до 10000 лк), а також виявляти стани очей користувача, що порушують правила тестування, для подальшої відповіді системи (пропуск запитання або запит на повторну автентифікацію).

Ключові слова: дистанційне навчання; тестування; надійність; оцінювання успішності; погляд; договір про надання освітніх послуг.