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MODELING THE MINDFULNESS PEOPLE'S FUNCTION BASED ON THE RECOGNITION OF BIOMETRIC PARAMETERS BY ARTIFICIAL INTELLIGENCE ELEMENTS

*The **subject matter** of this article is the processes of modeling the function of attentiveness of users of critical applications on the basis of recognition of biometric parameters by elements of artificial intelligence. The **goal** is the development and software implementation of mechanisms for monitoring the work of employees of responsible professions, which, based on the analysis of information from a webcam online, monitor the presence of the employee's focus on the active zone of the critical application and the absence of unauthorized persons near the computer. The **tasks** to be solved are as follows: to determine a list of factors, the presence of which must be constantly checked to control the focus of the employee's attention on the active zone of the critical application and the absence of unauthorized persons near the computer; to choose the optimal technology for reading and primary processing of information from webcams online, for further use in solving the task; to develop mechanisms for monitoring certain factors, the presence of which must be constantly checked to control the presence of the employee's focus on the active zone of the critical application and the absence of unauthorized persons near the computer; and to programmatically implement the developed mechanisms using the object-oriented programming language Python. The **methods** used were artificial neural networks, 3D facial modeling, and landmark mapping. The following **results** were obtained. A list of factors has been identified, the presence of which must be constantly checked to monitor the presence of employee's attention in the active zone of critical use and the absence of unauthorized persons near the computer. On the basis of the analysis of modern technologies for reading and primary processing of information from online webcams, technologies implemented in the MediaPipe library were selected for further use in solving the problem. Mechanisms have been developed for monitoring certain factors, the presence of which must be constantly checked to monitor the presence of employees in the active zone of critical use and the absence of unauthorized persons near the computer. The object-oriented programming language Python is software-implemented using the MediaPipe library, mechanisms are developed and, based on the results of the experiments, the expediency of its use for solving the problem is proved. **Conclusions.** The scientific novelty of the obtained results is as follows: we have formed a list of factors, the presence of which must be constantly checked to monitor the presence of employee's attention in the active zone of critical application, the absence of unauthorized persons near the computer, and improved facial recognition technologies, which allows us to obtain a solution to the problem of monitoring the attention of users of critical applications in non-ideal conditions.*

Keywords: *critical application; facial geometry; map of landmarks; mindfulness; MediaPipe; neural networks.*

Introduction

Motivation. Nowadays, computerization already has taken place in almost all spheres of life. However, the degree of human involvement in this process and the requirements for the employee concerned in different cases differ quite significantly. There are several professions in which the constant presence of an employee’s focus on the active zone of a critical application is critical. Examples of such professions include air traffic controller, nuclear power plant operator, physical security control operator, and others. For such professions, it is necessary to consider the possibility of the influence of human factors, that is, a person may get tired or get sick or may be distracted by some subjective or objective factors. In such cases, the employee may lose attention, for example, fall asleep at the workplace, look not at the monitor but at the phone, through the window, or at another person. At the same time, their focus on the information displayed on the computer screen is lost, which can often be unacceptable. Therefore, there is an urgent need to solve the **scientific and applied problem of** monitoring the presence of the employee’s focus on the active zone of the critical application and the absence of unauthorized persons near the computer.

State of the art. To solve this problem, a set of technological solutions is used. Monitoring the attentiveness of employees in relevant responsible professions is a necessary and urgent task. Because we are talking about a person, it is advisable to use biometric technologies to analyze his/her attentiveness. If, due to his/her professional duties, a person works most of the time on the keyboard, then it is advisable to analyze his/her keystroke [1]; if the work is related to the input of information using devices with a touch screen, then it is advisable to analyze its handwriting [2, 3]; if a person should pay most attention to the information on the monitor, then it is advisable to use recognition technologies by face geometry [4 - 6]; if a person has a small mobile device, then it is advisable to use fingerprint recognition technologies [7, 8]; sometimes it is advisable to introduce additional authentication, which can be recognition of either the geometry of the palm [9] or voice [10] of the user. Of interest is a novel deep face recognition framework that consists of a feature restoration network, a feature extraction network, and an embedding matching module [11]. For example, COVID has identified the need to develop a robust system capable of detecting people not wearing face masks and recognizing different persons while wearing the face mask [12]. Also, the detection and recognition of objects in images using neural networks is an effective mechanism for solving various problems in such important fields as medicine [13] and transport [14]. After analyzing the relevant technologies and ready-made software solutions for information processing [15] based on neural networks [16] to identify [17] and confirm [18] authenticity that exist in open access on the Internet, we can conclude that at the moment there is no system for monitoring the attentiveness of employees based on the analysis of the geometry of their faces, which would fully perform the task. Therefore, this work is devoted to the task of monitoring the attentiveness of employees of responsible professions precisely on the basis of an analysis of the characteristics of their faces. In addition, given that we are talking about employees of precisely responsible professions, in many cases it is advisable not only to control their attentiveness but also to check the presence of more than one person at the computer. In other words, if any confidential information is displayed on the computer screen, the presence of an unauthorized person near the computer can lead to a violation of confidentiality. In addition, this person can distract the employee whose monitoring is performed. Given that nowadays almost all computers are equipped with webcams (built-in or additionally connected), it is advisable to use this particular device to implement the aforementioned control.

Objective and approach. Based on all the above, the following goal of this work was formulated: to develop and programmatically implement mechanisms for monitoring the work of employees of responsible professions, which, based on the analysis of information from a webcam online, monitors the presence of the employee's focus on the active zone of the critical application and the absence of unauthorized persons near the computer. To achieve this goal, it is necessary to solve the following tasks:

1. Determine the list of factors that need to be constantly checked to monitor the focus of the employee's attention on the active zone of the critical application and the absence of unauthorized persons near the computer.
2. On the basis of the analysis of modern technologies for reading and primary processing of information from webcams online, choose the optimal technology for further use in solving the task.
3. Develop mechanisms for monitoring certain factors, the presence of which must be constantly checked to control the focus of the employee's attention on the active zone of the critical application and the absence of unauthorized persons near the computer.
4. Programmatically implement the developed mechanisms and explore the feasibility of their use to solve the problem.

This article is devoted to solving the components of this urgent problem.

1. Case study

1.1. Determine the list of factors

To solve the first task, it is necessary to determine which features that can be identified by analyzing the image from the webcam can serve as signs of the employee’s loss of attention, that is, loss of focus of attention on the active zone of the critical application and signs of the presence of unauthorized persons in front of the webcam.

To check for the absence of unauthorized persons near your computer, it is advisable to check the number of faces whose images the system can extract from the information transmitted from the webcam. The selection of more than one face image, respectively, indicates not only an authorized user near the computer.

To control whether an employee focuses on the critical application core, it is advisable to monitor the following factors:

- the presence of the absence of an employee at the computer;
- the presence of a significant turn or tilt of the employee’s head;
- the presence of closed eyes, which may indicate that the person is sleeping;
- the presence of a deviation in the direction of the person's gaze from the monitor in the other direction.

That is, when solving the first problem, the user activity function (1) was built, which includes several functions, the mechanisms for implementing which are defined below:

$$C_{act\_user} = f_{act\_user}(User_{num\_face}, User_{head\_pos}, User_{open\_eye}, User_{iris\_dir}), \quad (1)$$

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where $User_{num\_face}$ – function for determining the number of faces in front of the webcam, $User_{head\_pos}$ – function for determining the position of the face (tilt, turn), $User_{open\_eye}$ – function of checking open eyes or closed, $User_{iris\_dir}$ – function of checking the direction of gaze.

Information about the presence of all these deviations should be immediately reported to the system administrators (or other persons responsible for this control) and stored in the appropriate electronic log for further analysis. In addition, in our opinion, the duration of the aforementioned deviations is fundamental. That is, if, for example, an employee's pen fell and he bent down to pick it up, or someone entered the room and the employee turned his/her head to see who entered, then this action lasts several seconds and usually does not lead to problematic deviations. However, if this employee searches for a fallen pen for several minutes or talks for several minutes with a person who entered the room, then this is already a longer deviation, which can lead to significant negative consequences. Accordingly, it is advisable to store in the electronic journal not all deviations but only those that last more than a certain critical period.

To date, there are already sufficient technologies for reading and processing information transmitted from webcams online and selecting the characteristics necessary for subsequent analysis. These technologies are used to solve various problems, including information protection, for example, to authenticate users of information systems [4, 8]. These technologies distinguish a different number of characteristic facial points, the parameters of which are then analyzed for recognition, have different principles of operation, have their advantages and disadvantages, but none of the technologies found in the public domain performs all the functions that are necessary to identify the previously described factors necessary to control the presence of the employee's focus on the active zone of the critical application and the absence of unauthorized persons near the computer. Therefore, when solving this problem in this paper, existing technologies are used to implement reading and primary processing of information from webcams, and appropriate special mechanisms are developed to implement the functions that are directly necessary to perform this monitoring.

1.2. Choose the optimal technology

To solve the second task, based on the analysis of modern technologies for reading and primary processing of information from webcams online, technologies implemented in the MediaPipe library were selected for further use: developers.google.com [19], samproell.io [20], and github.com [21]. In addition, we considered technologies of Face Recognition and Mobile Vision by OpenCV [22], FaceNet [23], and MobileNets [24]. This choice is justified for the following reasons:

1. MediaPipe library uses machine learning, which provides a clearer and more constant finding of facial landmarks, unlike OpenCV, which uses the method of comparison with ready-made templates.
2. In MediaPipe library, 468 3D facial landmarks are defined (Fig. 1), which is much more than, for example, in OpenCV (only 67) [22], thereby providing more functionality in determining and analyzing various characteristics of the face and greater accuracy in determining these characteristics.
3. MediaPipe library provides high performance in real time, which is critical in solving the problem of monitoring (continuous recognition).
4. In MediaPipe library it is possible to find landmarks of the iris, which is absent, for example, in OpenCV, but is very useful for controlling the parameters necessary to solve tasks.

Consider the main principles of the functioning of technologies implemented in the MediaPipe library [19] and indicate which function from this library and for what exactly was directly used in the developed system. From the selected MediaPipe library, the Face Mesh function was used. This function determines 468 3D landmarks (points with coordinates) of the face in real time and with its help, accesses an array of integer values of the coordinates of these landmarks of the face [21]. The map of these landmarks, with their numbers, is publicly available, and they never change. For example, in the center of the right eye there is always a marker with the number 473, and in the center of the left eye there is a marker with the number 468 [21]. This fact greatly facilitates the selection of the coordinates of a specific marker (landmark). The coordinates of these landmarks (markers) will be further analyzed in the corresponding developed functions for solving the tasks. The function uses neural networks to determine the 3D surface of the face. Using facial model architecture and GPU acceleration throughout the processing pipeline, the function delivers high real-time performance. Face Mesh [25] uses a pipeline of two neural networks to determine the 3D coordinates of 468 facial landmarks: psevdo three-dimensional coordinates from a two-dimensional image. The first neural network "BlazeFace" finds the location of the face based on the analysis of the full image. BlazeFace uses a lightweight feature extraction network similar to MobileNetV1/V2 [26].

On the left is a block of a conventional convolutional network, and on the right is the basic block of MobileNet (Fig. 1) [27].

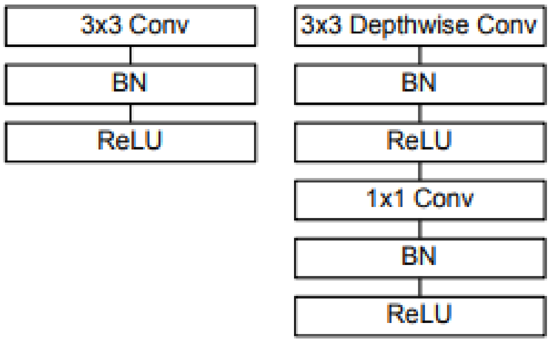

Fig. 1. MobileNetV1

The convolutional part of the network of interest consists of one ordinary convolutional layer with a 3x3 convolution at the beginning and thirteen blocks shown on the right in the figure, with a gradually increasing number of filters and a decreasing spatial dimension of the tensor.

A feature of this architecture is the absence of max pooling layers. Instead, to reduce the spatial dimension, a convolution with a stride parameter equal to 2 is used.

The second neural network allows you to determine the area (shape) of the face by selecting it from any input image. The second neural network uses a statistical analysis technique called Procrustes Analysis and selects and analyzes the area of the found face to determine its landmarks along with the first network. This computational circuit in the form of a conveyor is built to provide high speed, so it can work on any device with built-in or external video cameras, not only on laptops or desktop computers, but also on mobile devices (phones, tablets, etc.) [20].

In the developed system, technology from the MediaPipe library was used only to find an image of one or several faces in the video stream and to find the coordinates of all facial landmarks (Fig. 2) [21]. To implement all other functions that are directly necessary to perform this monitoring, appropriate special mechanisms have been developed.

1.3. Develop mechanisms for monitoring certain factors

The third task, as you can see, consists of five components.

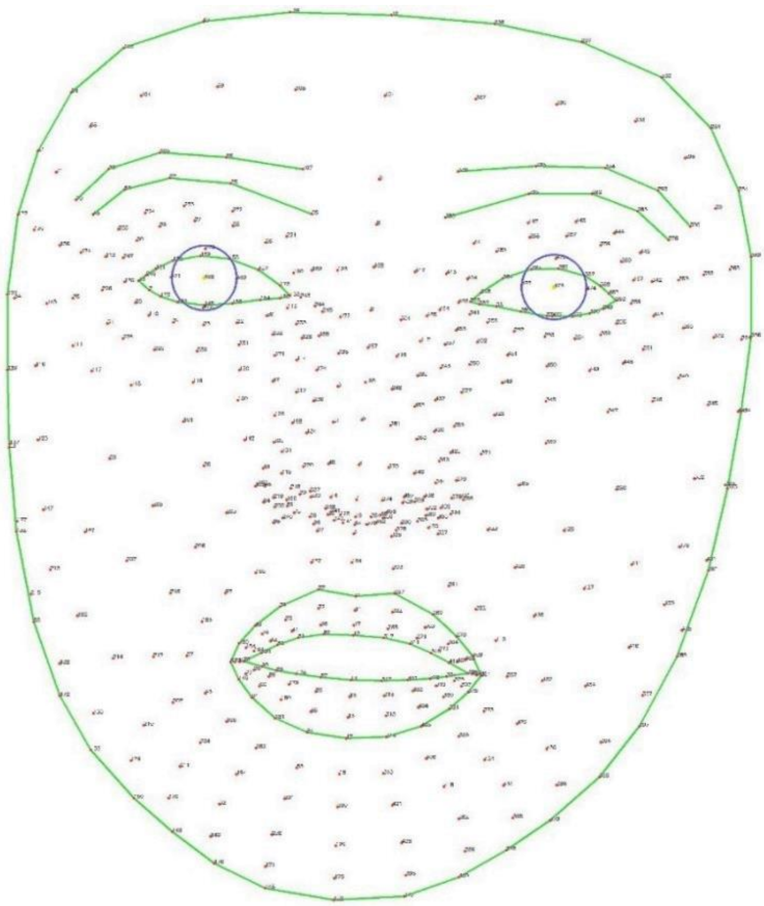

Fig. 2. Location of face landmarks in MediaPipe library face model

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In the first step of this monitoring system, *the first and second components of the third task are solved*, namely, the absence of a face in front of the webcam or the presence of several faces in front of the camera are detected. For this purpose, the function of determining the number of faces in front of the webcam is built $User_{num\_face}$ (2):

$$User_{num\_face} = f_{num\_face}(NF_{mark\_face}, NF_{line\_face}, NF_{count\_face}, NF_{max\_face}), \quad (2)$$

where NF_{mark_face} – face marker detection function, NF_{line_face} – outline function of found faces, NF_{count_face} – function for determining the number of faces found, NF_{max_face} – function for determining the largest face image.

If several faces are found, their number is counted and more faces are determined. To perform this tracking, the following steps were taken:

1. The function NF_{mark_face} determines the location of face landmarks in the image and forms an array (several arrays) of landmarks of found faces with their coordinates. To do this, use the multi_face_landmarks function (from the MediaPipe library), which receives information from the camera as input and returns an array (or several arrays) with landmarks (points) of the face and their coordinates.

2. The function NF_{line_face} outlines the contours of all found faces with ovals (highlighting). For this purpose, the coordinates of the landmarks of the contours of the found faces are used. The outline of the face has 36 landmarks, which, as can be seen in Fig. 2, have the following numbers: 10, 338, 297, ..., 67, 109.

3. Functions NF_{count_face} counts the number of landmark arrays of the found faces, thus determining the number of faces in front of the camera. As mentioned earlier, if there is no person's face in front of the camera then accordingly this indicates a loss of focus of the employee's attention, and if more than one face is detected, this indicates the presence of unauthorized persons in front of the camera.

4. The function NF_{max_face}, using the appropriate coordinates, determines the largest face and in the further work of the program only the data of the array of the largest face is used, assuming that this person belongs to an authorized employee.

After selecting the contour of the authorized user's face and determining the coordinates of the landmarks of his/her face, *the third component of the third task is solved*, namely, the facts *of tilts and turns of the head* are detected. For this purpose, the function of determining the position of the face (tilt, rotation) is built $User_{head\_pos}$ (3):

$$User_{head\_pos} = f_{head\_pos}(HP_{koord\_mark}, HP_{kord\_centr}, HP_{znak\_tiy\_tux}, HP_{koord\_centr\_eye}, HP_{tilt\ angle}, HP_{znak\_tix}), \quad (3)$$

where HP_{koord_mark} – function of determining the coordinates of the corresponding landmarks, HP_{koord_centr} – function of determining the coordinates of the center of the face, $HP_{znak\_tiy\_tux}$ – function of conclusions based on the analysis of signs of projections of vectors, $HP_{koord\_centr\_eye}$ – function of determining the coordinates of landmarks of eye centers, HP_{tilt_angle} – function of determining the angle of inclination of a straight line passing through the middle of the eyes, HP_{znak_tix} – function of conclusions based on the analysis of the angle of inclination.

To detect *face turns left / right and tilts up / down*, this system tracks the vectors of face tilt up / down and face rotation left / right, which are determined by signs ("+" or "-") of projections on the X and Y axes of the vector from the nose landmark to the center of the face.

When the face is in a normal position, then, in the "front view" projection, the image of the nose is almost in the center of the face image and, accordingly, the projections of the vector have almost zero values; if the face is tilted up/down or turned left/right, then, in the "front view" projection, the values of the projections (one or both) of the vector are significantly increased and, in this case, the signs of the projections of the vector on the X and Y axes can draw conclusions about the direction of inclination and rotation of the head. To perform this tracking, the following steps were taken:

1. The function HP_{koord_mark} determines the necessary coordinates of the corresponding landmarks (Fig. 2), namely, the X and Y coordinates of the nose marker $(N\_x,\ N\_y)$, X coordinates of the markers of the upper and lower borders of the face and the Y coordinates of its left and right borders, respectively $(T\_x,\ B\_x,\ L\_y,\ R\_y)$. Based on the analysis, the following landmarks were used to determine the center of the face: 151, 199, 177, and 401. To determine the position of the nose, landmark number 4 was used.

2. The coordinates of the center of the face are determined in the function HP_{koord_centr} (only whole parts of the results will be used) (4):

$$C\_x = int(\frac{B\_x + T\_x}{2}),\ C\_y = int(\frac{L\_y + R\_y}{2}), \quad (4)$$

where int() – function of finding the integer part of the argument, C_x and C_y – coordinates X and Y center of the face, respectively.

3. The function $HP_{znak\_tiy\_tux}$ determines the projections on the X and Y axis of the vector from the nose landmark to the center of the face, performs the necessary corrections of the found projections of the vector and draws conclusions regarding the presence of facts of the face turning left/right and tilting up/down (5). Considering the location of these markers and the placement of the face in a normal position relative to the laptop webcam, the following vector projection correction variables were introduced according to the corresponding coordinates: $K\_x,\ K\_y$:

$$\begin{gathered} D\_y = N\_y - C\_y + K\_y, \\ D\_x = N\_x - C\_x + K\_x, \\ TI\_tb = \begin{cases} \text{UP, if } D\_y < -20, \\ \text{CENTRE, if } -20 \le D\_y \le 20, \\ \text{DOWN, if } D\_y > 20, \end{cases} \\ TU\_lr = \begin{cases} \text{LEFT, if } D\_x < -10, \\ \text{CENTRE, if } -10 \le D\_x \le 10, \\ \text{RIGHT, if } D\_x > 10, \end{cases} \end{gathered} \quad (5)$$

where D_x and D_y – axis projections X and Y vector from the nose landmark to the center of the face, respectively, $K\_x = -3$ and $K\_y = 5$ – correction of vector projection on the axis X and Y, respectively, TI_tb – is the direction of inclination of the face vertically, TU_lr – is the direction of rotation of the face horizontally.

To detect the inclinations of the face to the left/right in this system, the angle of inclination of the straight line passing through the points of the middle of the eyes is analyzed. When the face is not tilted left/right, this line is parallel to the horizontal coordinate axis. Accordingly, the angle between this straight line and the horizontal is a sign of tilting the face to the left or right. To perform this tracking, the following steps were taken:

1. The function $HP_{koord\_centr\_eye}$ determines the necessary coordinates of the corresponding landmarks (Fig. 2), namely, the X and Y coordinates of the middle markers of the left and right eyes, respectively $(LE\_x,\ LE\_y,\ RE\_x,\ RE\_y)$. As already noted, in the center of the eyes are markers with numbers 468 and 473 (Fig. 2).

2. The function HP_{tilt_angle} determines the angle of inclination of the line passing through the points of the middle of the eyes relative to the horizontal axis of coordinates and converts the result from radians to degrees (only the integer part of the result will be used) (6):

$$\begin{gathered} GN = \text{int}(\text{degress}(\text{atan2}(RE\_y - LE\_y, \\ RE\_x - LE\_x))), \end{gathered} \quad (6)$$

where degrees() – function for converting the value of the argument from radians to degrees, atan2() – arctangent function for the specified arguments, GN – the angle of inclination of the straight line passing through the points of the middle of the eyes.

3. The function $HP_{koord\_centr\_eye}$ Depending on the value of the found angle of inclination (6), conclusions are made regarding the inclination of the face to the left / right (7):

$$TI\_lr = \begin{cases} \text{LEFT, if } GN < -10, \\ \text{CENTRE, if } -10 \le GN \le 10, \\ \text{RIGHT, if } GN > 10, \end{cases} \quad (7)$$

where TI_lr – direction of inclination of the face horizontally.

The values of all coefficients used and coordinate correction variables, when revealing the aforementioned facts of inclinations and turns of the face, were determined experimentally and may require adjustment, considering the anatomical features of the faces of the organization's employees and the placement of the webcam at their workplaces.

To solve *the fourth component of the third task*, i.e., to detect closed eyes, this system monitors the relationship between the distance between the eyelids of the corresponding eye and the distance between two selected points on the face. For this, the function of checking open eyes or closed is built $User_{open\_eye}$ (8):

$$\begin{gathered} User_{open\_eye} = f_{open\_eye}(OE_{koord\_eye}, OE_{line\_eye}, \\ OE_{coef\_eye}, OE_{concl\_eye}), \end{gathered} \quad (8)$$

where OE_{koord_eye} – the function of determining the coordinates of the corresponding landmarks, OE_{line_eye} – the function of determining the lengths of segments, OE_{coef_eye} – the function of determining the coefficients of eye closure, OE_{concl_eye} – the function of conclusions.

The choice to compare the distance between two points of the face, instead of some stable value, is necessary for the correct operation of the program when turning and tilting the face and when a person is at an

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arbitrary distance from the webcam. Segments between the corresponding markers (159 and 145, 193 and 417), the ratio of which is examined to check whether the left eye is closed (for example), are shown in Fig. 3.

To perform this tracking, the following steps were taken:

1. The function OE_{koord_eye} determines the necessary coordinates of the corresponding landmarks (Fig. 2), namely, the Y coordinates of the upper and lower eyelid markers of the left and right eyes, respectively $(LET\_y, LEB\_y, \; RET\_y, REB\_y)$ and the X coordinates of the two selected points on the face, respectively (LT_x, RT_x). To determine the upper and lower eyelids of the left eye and the upper and lower eyelids of the right eye, the following landmarks were used, respectively: 159, 145, 386, 374; The points between which the segment was used for this comparison were chosen landmarks 193 and 417.

2. The function OE_{line_eye} determines the lengths of the segments between the eyelids of the left eye, between the eyelids of the right eye, and between two selected points of the face, the distance between which is used for comparison (9):

$$\begin{aligned} V\_LE &= LET\_y - LEB\_y, \\ V\_RE &= RET\_y - REB\_y, \\ TT &= RT\_x - LT\_x, \end{aligned} \qquad (9)$$

where V_LE and V_RE – distances between the upper and lower eyelids of the left and right eyes, respectively, TT – is the distance between the two selected points used for comparison.

3. The function OE_{coef_eye} determines how many times the length of the segment between the selected points of the face is greater than the distance between the eyelids of the left eye and how many times it is greater than the distance between the eyelids of the right eye (10):

$$K\_LE = \frac{TT}{V\_LE}, \; K\_RE = \frac{TT}{V\_RE}, \qquad (10)$$

where K_LE and K_RE – coefficients of closure of the left and right eyes, respectively.

4. The function OE_{concl_eye} conclusions are drawn whether the left eye is closed and the right eye is closed. To do this, analyze the closeness coefficients of the left and right eyes and how significantly the face is turned left / right (if the turn is not maximum) (11):

$$\begin{aligned} ZLE &= \begin{cases} \text{OPENED, if } K\_LE < 2.2 \wedge D\_x > -25, \\ \text{CLOSED, if } K\_LE \geq 2.2 \vee D\_x \leq -25, \end{cases} \\ ZRE &= \begin{cases} \text{OPENED, if } K\_RE < 2.2 \wedge D\_x < 25, \\ \text{CLOSED, if } K\_RE \geq 2.2 \vee D\_x \geq 25, \end{cases} \end{aligned} \qquad (11)$$

where ZLE and ZRE – signs of whether the left and right eyes are closed, respectively. The value of "2.2" with which ZLE and ZRE, are compared, has been determined experimentally and may need to be adjusted considering the anatomical features of the faces of employees of the organization, in which case the eye should be considered closed.

To solve *the fifth component of the third task*, namely to detect the deviation of the direction of a person's gaze from the monitor in the other direction, this system analyzes for each eye signs ("+" or "-") of projections on the X and Y axes of the vector from the center of the iris to the center of the eye. This action is possible if at least one of the eyes is open. For this purpose, the function of checking the direction of gaze is built $User_{iris\_dir}$ (12):

$$User_{iris\_dir} = f_{iris\_dir}(ID_{open\_eye}, ID_{koord\_mark}, ID_{koord\_centr}, ID_{znak\_concl}), \qquad (12)$$

where ID_{open_eye} – function to check for at least one open eye, ID_{koorf_mark} – the function of determining the coordinates of the corresponding landmarks, ID_{koorf_centr} – function for determining the coordinates of the centers, ID_{znak_concl} – the function of inferences based on the analysis of signs of vector projections.

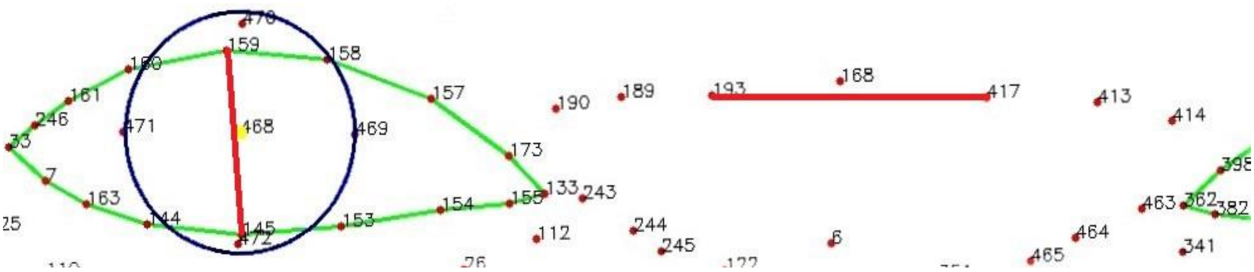

Fig. 3. Segments whose ratios are analyzed to determine whether the left eye is closed

To perform this tracking, the following steps were taken:

1. The function ID_{open_eye} checks if at least one of the two eyes is open (13):

$$ZLE = OPENED \vee ZRE = OPENED. \qquad (13)$$

If this condition is performed, then the transition to the next step of the algorithm is carried out; otherwise, if both eyes are closed, then, as shown in the fourth step of the algorithm, the gaze is directed downwards (we can conclude that there is no possibility to determine the direction of the gaze).

2. The function ID_{koorf_mark} determines the necessary coordinates of the corresponding landmarks (Fig. 2), namely, the X coordinates of the left and right border markers of the left eye and the Y coordinates of the markers of its upper and lower boundaries, respectively $(LLE\_x,\ TLE\_y,\ RLE\_x,\ BLE\_y)$; namely, the X coordinates of the left and right border markers of the right eye and the Y coordinates of the markers of its upper and lower boundaries, respectively $(LRE\_x,\ TRE\_y,\ RRE\_x,\ BRE\_y)$, coordinates X and Y of the left and right border iris of the left eye, respectively $(LLR\_x,\ LLR\_y,\ RLR\_x,\ RLR\_y)$, coordinates X and Y of the left and right border iris of the right eye, respectively $(LRR\_x,\ LRR\_y,\ RRR\_x,\ RRR\_y)$. For these actions, markers of the edges of the eyes and iris were used, namely, the following markers were used to determine the centers of the left eye and right eye, respectively: 33, 133, 159, 145 and 362, 263, 386, 374; To determine the centers of the iris of the left eye and right eye, the following markers were used, respectively: 471, 469 and 476, 474.

3. The function ID_{koorf_centr} determines the coordinates of the centers of the left eye, right eye, iris of the left eye, and iris of the right eye (only whole parts of the results will be used) (14):

$$\begin{aligned}
C_LE_x &= \mathrm{int}(\frac{LLE_x + RLE_x}{2}),\\
C_LE_y &= \mathrm{int}(\frac{TLE_y + BLE_y}{2}),\\
C_RE_x &= \mathrm{int}(\frac{LRE_x + RRE_x}{2}),\\
C_RE_y &= \mathrm{int}(\frac{TRE_y + BRE_y}{2}),\\
C_LR_x &= \mathrm{int}(\frac{LLR_x + RLR_x}{2}),\\
C_LR_y &= \mathrm{int}(\frac{LLR_y + RLR_y}{2}),\\
C_RR_x &= \mathrm{int}(\frac{LRR_x + RRR_x}{2}),\\
C_RR_y &= \mathrm{int}(\frac{LRR_y + RRR_y}{2}),
\end{aligned} \qquad (14)$$

where C_LE_x and C_LE_y – coordinates X та Y center of the left eye, C_RE_x and C_RE_y – coordinates X and Y center of the right eye, C_LR_x and C_LR_y – coordinates X and Y center of the iris of the left eye, C_RR_x and C_RR_y – coordinates X and Y center of the iris of the right eye.

4. The function ID_{znak_concl} projections on the X and Y axis of the vector from the center of the iris to the center of the eye were determined for each eye, based on the analysis of the sign ("+" or "-") of which conclusions were made regarding the deviation of the direction of the person's gaze from the monitor in the other direction (15):

$$IT\_x = \begin{cases} \text{CENTRE, if } -3 \le (C\_LR\_x\text{-}C\_LE\_x) \le 3 \wedge \\ \wedge -3 \le (C\_RR\_x\text{-}C\_RE\_x) \le 3, \\ \text{LEFT, if } (C\_LR\_x\text{-}C\_LE\_x) < -3 \vee \\ \vee (C\_RR\_x\text{-}C\_RE\_x) < -3, \\ \text{RIGHT, if } (C\_LR\_x\text{-}C\_LE\_x) > 3 \vee \\ \vee (C\_RR\_x\text{-}C\_RE\_x) > 3, \end{cases}$$

$$IT\_y = \begin{cases} \text{CENTRE, if } (C\_LR\_y\text{-}C\_LE\_y+1) \ge -1 \wedge \\ \wedge (C\_RR\_y\text{-}C\_RE\_y+1) \ge 0, \\ \text{UP, if } (C\_LR\_y\text{-}C\_LE\_y+1) < -1 \vee \\ \vee (C\_RR\_y\text{-}C\_RE\_y+1) < 0, \\ \text{DOWN, if } ZLE = CLOSED \wedge \\ \wedge ZRE = CLOSED, \end{cases} \qquad (15)$$

where IT_x and IT_y – horizontal and vertical viewing directions, respectively. The numerical values under these conditions were determined experimentally and are not recommended to be changed because there is a very small data limit available to assess the direction in MediaPipe (this is a disadvantage of this technology), that is, because the calculations occur in the coordinate system, the number of integer values of the position of the iris varies within small limits (by 1-2 units)

1.4. Programmatically implement the developed mechanisms

To solve *the fourth task*, on the basis of the MediaPipe library and using the object-oriented programming language Python, the developed mechanisms were programmatically implemented. The expediency of their use to solve the problem is confirmed by the results of the experiments.

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To visualize the results of the software application, the following is done in the developed system:

1. The values of all factors, the presence of which is checked by the system to solve the task, are displayed in the corresponding window of the system interface near the information transmitted online from the webcam.

2. The contours of all found faces are circled (highlighted) with ovals, based on the analysis of the coordinates of the contour markers of the found faces. As noted earlier, all further actions are performed only for the largest of the found faces, assuming that this person belongs to an authorized person.

3. The circles of the contours of the iris of open eyes and rectangles of the contours of closed eyes are circled, and a conclusion is made regarding the status of the eyes. Namely, if it was recorded that the eye is open, then the contour of its iris is circled and information is displayed that the eye is open. If it was recorded that the eye is closed, then a rectangle is drawn around the eye (if the eye is completely present in the image) and the fact of maximum head rotation or tilt is analyzed. If the head is turned to the right or left as much as possible (the eye is not present in the image), then information is displayed that the eye is not found. If the head is significantly tilted down (the eyelids cover the image of the iris), then information is displayed that the eye is looking down. If the face is in the central position (but the fact of a closed eye is recorded), then information is displayed that the eye is closed.

In addition, as noted earlier, it is advisable to check the duration of deviations of these factors from the norm and fix them in the system only if this duration is significant. In this system, it was experimentally determined that it is advisable to set a limit value of the specified duration of 7 s, but depending on the requirements for the level of care of the employee in a particular organization, this value can be changed. Accordingly, if a deviation of one of the specified parameters was recorded, then the timer is activated in the system. If within seven seconds the value of this parameter or other parameter has not normalized, for which a deviation is also recorded during this time, then in the catalog with the results of logging a file is stored an image file of a person's face in the moment data with fixed values of all analyzed characteristics and those parameters whose values deviated from the norm, highlighted in red. The name of this file displays the date and exact time of the deviation recorded. In addition, a text log file is created every day, in which, for each recorded deviation greater than 7 s, an entry consisting of the time of the beginning of the rejection is added; the time when it was last fixed; username; and values of all previously mentioned characteristics analyzed. Such logging of all fundamental deviations is necessary for subsequent analysis of the employee's work or to identify the causes of any emergencies.

The results of performing the main functions of the developed system are demonstrated in the figures in the experimental part of this article.

Note that in the technologies of the MediaPipe library, there is functionality, which, depending on the task for which the technology is used, can be both an advantage and a disadvantage. For example, this technology provides that if all markers of some part of the face cannot be recognized, then the part of the face is "modeled" according to the average statistical coordinates of the corresponding markers of the human face. When solving many problems, this property is useful; however, when you need to check the eyes closed or open or determine the direction of gaze, this complicates the process of solving the problem. It would be much easier to analyze the coordinates of iris markers to solve these problems; however, if the eye is closed and, accordingly, the iris is not visible, then the system, instead of fixing this fact, will predict where this part of the face should be located and in that place will "draw" the iris (even when the eye is closed). These features of MediaPipe were incorporated into the developed system using appropriate algorithmic and software solutions.

2. Testing the feasibility of using the developed system

To test the feasibility of using the developed system and identify its advantages and disadvantages, several experiments were conducted. The experiments were conducted under different lighting conditions on different computers on which webcams with different technical characteristics were installed. During the experiments, the system was tested under the following conditions:

1. In the presence of the following deviations:
   - there are several people in front of the webcam;
   - no person is in front of the webcam;
   - the employee turned his/her head to the right/left;
   - the employee tilted his/her head to the right / left / up / down;
   - the employee closed his/her left eye / right eye / both eyes;
   - the employee is not looking at the active zone of the critical application, but to the right/left/up/down from the computer screen.
2. In the presence of deviations simultaneously, there are several signs.
3. In the absence of any of these deviations.
4. If there are glasses on the employee's face.

During the experiments, the program window displayed online webcam information and the values of all controlled characteristics and highlighted the contours of faces and the outlines of open and closed eyes (in different ways) of an authorized person. If the recorded deviations lasted more than 7 s, then in the catalog with the results of logging, an image file of a person’s face was stored in the moment data with the fixed values of all analyzed characteristics, and those parameters whose values deviated from the norm were highlighted in red. The name of this file displays the date and exact time of the deviation recorded. In addition, a text log file was created each day, in which, for each recorded deviation greater than 7 s, an entry was appended that consisted of the time the rejection began; the time when it was last fixed; username; and values of all previously mentioned characteristics analyzed.

The main results of the experiments are presented in Figures 4-9. Consider them in more detail.

Figures 4-7 show the window of the developed monitoring system, on the right side of which information transmitted online from a webcam is displayed. On the left side, the values of all controlled parameters are indicated.

Fig. 4 shows an experiment in which there are two people in front of a webcam. Simultaneously, the system recorded this fact ("Faces found: 2"), circled the contours of both faces with ovals, but further analysis was carried out only to image a larger face, assuming that this face belongs to an authorized employee. Namely, in the image of the larger face, the iris of the eyes is circled, indicating that the eyes are open. In addition, the face was recorded tilted upwards («Face tilted to the UP»).

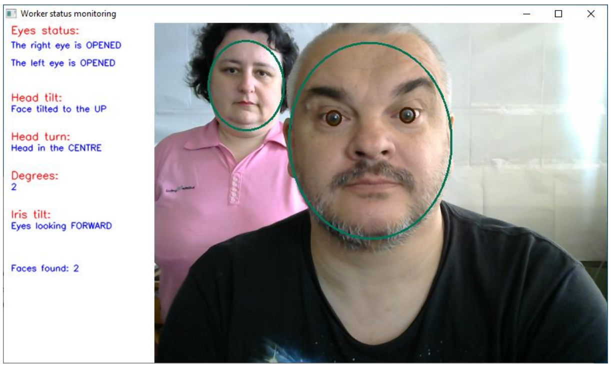

Fig. 4. Two faces found, larger face tilted upwards

Fig. 5 shows an experiment in which the monitoring system recorded that the employee in front of the webcam has a closed right eye ("The right eye is CLOSED"), respectively, it is circled by a rectangle; face tilted up and to the right ("Face tilted UP to the RIGHT"); the value of the angle of inclination of the face to the right ("Degrees: 29"); gaze pointing upwards ("Eyes looking UP").

Fig. 6 demonstrates an experiment in which the monitoring system recorded that the employee in front of the webcam had his/her face turned to the right ("Head turned to the RIGHT"); due to the large angle of rotation of the face to the right, the image of the face in the projection "front view" did not find the image of the right eye ("The right eye NOT FOUND"); gaze to the right ("Eyes looking RIGHT").

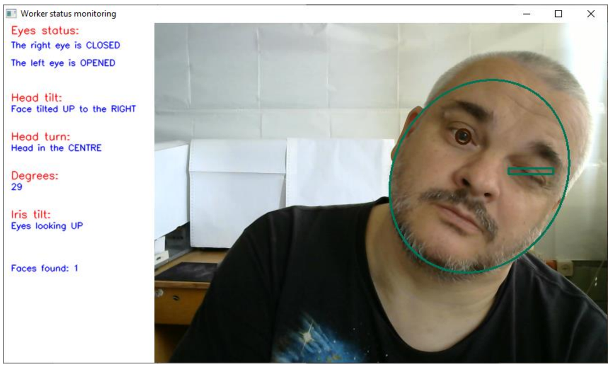

Fig. 5. The right eye is CLOSED

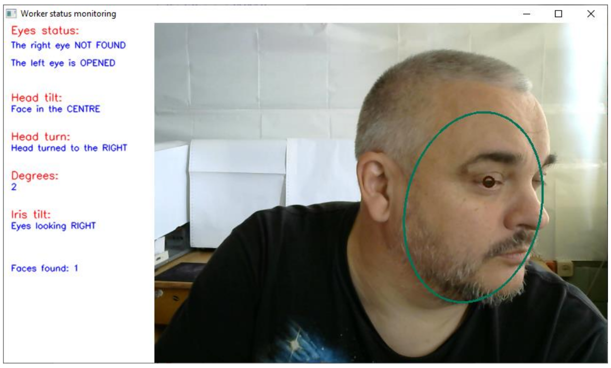

Fig. 6. Head turned to the RIGHT

Fig. 7 shows an experiment in which the monitoring system recorded that the employee in front of the webcam had his/her face tilted upwards ("Face tilted to the UP"). This experiment demonstrates that when using the developed system, the presence of glasses on the employee's face does not affect the reliability of determining all the characteristics necessary to solve the tasks.

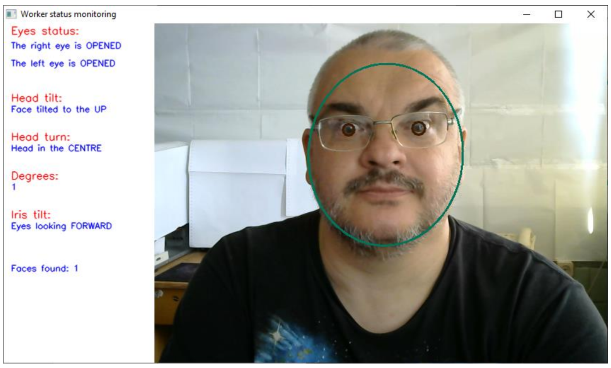

Fig. 7. Glasses on the employee's face

Fig. 8 shows the image stored in the file in the directory with the log results, if the deviation of one or

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more parameters lasted more than 7 s. The top of this image displays information that was transmitted online from the webcam at the time of fixing the fact that the deviation lasted more than 7 s. At the bottom of this image, the values of all controlled parameters are indicated, and those parameters whose values deviated from the norm are highlighted in red. In the experiment, the results of which are demonstrated in this image, the monitoring system recorded that the employee in front of the webcam has a closed right eye ("The right eye is CLOSED"), respectively, it is circled by a rectangle; face tilted up and to the right ("Face tilted UP to the RIGHT"); the value of the angle of inclination of the face to the right ("Degrees: 16"); face turned to the right ("Head turned to the RIGHT"); gaze pointing upwards ("Eyes looking UP").

Fig. 8. The right eye is CLOSED, an image stored in a log file

The developed monitoring system every day, when fixing the first deviation lasting more than 7 s, creates a text log file in which, for each recorded deviation greater than the specified time interval, an entry is added, which consists of the time of the beginning of the deviation; the time when it was last fixed; username; and values of all previously mentioned characteristics analyzed. An example of such a file is shown in Fig. 9.

In addition, through experimental studies, appropriate values of numerical coefficients and variable corrections, which were used in the developed functions, were established. However, in each particular organization, it may be advisable to adjust some of these values in accordance with the anatomical features of the faces of the employees of this organization.

3. Discussion

This paper describes factors that allow you to control the focus of the employee's attention. The results of this work complement and do not contradict the theory of face recognition.

Using technology from library MediaPipe made it possible to control the absence or shift in the focus of attention left/right/up/down from the workspace of the critical application, the presence of multiple people in front of the camera, and the absence of an operator in the work area.

The implementation of these functions made it possible to organize control over the presence of the employee's focus of attention on the active zone of the critical Application.

A negative factor revealed the need for individual adjustment of parameters recognition of critical situations, in particular the size of the gap between the upper and lower eyelids user in the process of work. During the experiments, it turned out that there was a need for individual settings of this parameter for different users. In the future, it is advisable to add an automatic configuration block to the system when the user changes.

The article showed the methods and mechanisms for solving the problem using modern means. The presence of such a system allows us to expand control over the user of applications and lays down the fundamentals of the development of the theory of identification of the focus of the user's attention.

```
Log_30_05_2023.txt: Блокнот
Файл Редагування Формат Вигляд Довідка
Output time: Detecting time: User: Face detection: Right eye status: Left eye status: Head tilt: Head turn: Degrees: Iris tilt: Faces found:

13:21:58; 13:21:51; TEST-W; Face detected; The right eye is CLOSED; The left eye is CLOSED; Face tilted to the UP; Head in the CENTRE; 2; Eyes closed; 2;

13:22:05; 13:21:51; TEST-W; Face detected; The right eye is OPENED; The left eye is CLOSED; Face in the CENTRE; Head in the CENTRE; 1; Eyes looking FORWARD; 2;

13:23:02; 13:21:51; TEST-W; Face detected; The right eye is CLOSED; The left eye is CLOSED; Face tilted UP to the LEFT; Head in the CENTRE; 6; Eyes closed; 1;

13:24:00; 13:23:14; TEST-W; Face detected; The right eye NOT FOUND; The left eye is CLOSED; Face in the CENTRE; Head turned to the RIGHT; 6; Eaes looking LEFT; 2;

13:25:51; 13:25:20; TEST-W; Face detected; The right eye is CLOSED; The left eye is OPENED; Face tilted UP to the RIGHT; Head turned to the RIGHT; 16; Eyes looking UP; 1;
```

Fig. 9. Sample text log file

Conclusions

To achieve the goal in the work, we solved the following tasks:

1. A list of factors has been identified, the presence of which must be constantly checked to control the presence of the employee's focus on the active zone of the critical application and the absence of unauthorized persons near the computer.
2. On the basis of the analysis of modern technologies for reading and primary processing of information from webcams online, the technologies implemented in the MediaPipe library were selected for further use in solving the problem.
3. Mechanisms for monitoring certain factors have been developed, the presence of which must be constantly checked to control the presence of the employee's focus on the active zone of the critical application and the absence of unauthorized persons near the computer.
4. Programmatically implemented object-oriented programming language Python using the MediaPipe library, the mechanisms were developed, and based on the results of the experiments, the expediency of its use for solving the problem was proved.

The developed system fully performs the task. Due to the developed and software-implemented technologies and a vast number of facial landmarks defined in MediaPipe, correct and accurate determination of the values of controlled features was achieved. The system works correctly even under poor light conditions. Some shortcomings inherent in the technologies in the MediaPipe library were leveled in the system with specially developed software solutions. These disadvantages, described in detail earlier, include the "modeling" of those parts of the face that cannot be recognized at the moment and the presence of some landmarks of the iris (with several landmarks of other parts of the face).

However, based on the results of the experiments, it was concluded that it is expedient to add to the system the possibility of setting in the program interface the value with which the coefficients of closing of the left and right eyes are compared (K_LE and K_RE) when determining whether the eyes are closed. This need may be caused by the anatomical features of the faces of employees of the organization; therefore, these settings should be made for each team of people, and possibly for each employee individually. In addition, it is advisable to ensure the possibility of displaying and storing monitoring results not on employees' computers but on the system server for administrator access to this information.

Future research directions are as follows:

1. Formalization of the description of the implementation of the control function to simulate its use.
2. Construction of the functional dependence of the completeness of control on the subject area to determine the limitations caused by the user's specialization.

Contributions of authors: formulation of the problem – **Olena Vysotska**; development of mechanisms for monitoring – **Olena Vysotska, Anatolii Davydenko, Oleksandr Potenko**; program realization of algorithm – **Oleksandr Potenko**; analysis of model problem, analysis results processing – **Anatolii Davydenko, Olena Vysotska**; text of preliminary version of the paper – **Olena Vysotska**; editing and postediting – **Anatolii Davydenko, Olena Vysotska**.

All authors have read and agreed to the published version of this manuscript.

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МОДЕЛЮВАННЯ ФУНКЦІЇ УВАЖНОСТІ ЛЮДИНИ НА ОСНОВІ РОЗПІЗНАВАННЯ БІОМЕТРИЧНИХ ПАРАМЕТРІВ ЕЛЕМЕНТАМИ ШТУЧНОГО ІНТЕЛЕКТУ

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Предметом вивчення в статті є процеси моделювання функції уважності користувачів критичних застосунків на основі розпізнавання біометричних параметрів елементами штучного інтелекту. **Метою** даної роботи є розробка та програмна реалізація механізмів моніторингу роботи співробітників відповідальних професій, які на основі аналізу інформації з веб-камери в режимі онлайн, здійснюють контроль наявності фокусу уваги співробітника на активній зоні критичного застосунку та відсутності неавторизованих осіб біля комп’ютера. **Завдання:** визначити перелік факторів, наявність яких необхідно постійно перевіряти для контролю наявності фокусу уваги співробітника на активній зоні критичного застосунку та відсутності неавторизованих осіб біля комп’ютера; обрати оптимальну технологію зчитування та первинної обробки інформації з веб-камер в режимі онлайн, для подальшого використання при вирішенні поставленої задачі; розробити механізми моніторингу визначених факторів, наявність яких необхідно постійно перевіряти для контролю наявності фокусу уваги співробітника на активній зоні критичного застосунку та відсутності неавторизованих осіб біля комп’ютера; програмно реалізувати розроблені механізмі за допомогою об’єктно-орієнтовної мови програмування Python. Використовуваними **методами** є: штучні нейронні мережі, 3D моделювання обличчя, побудова мапи орієнтирів. Отримані такі **результати.** Виявлено перелік факторів, наявність яких необхідно постійно перевіряти для контролю наявності уваги співробітника на активній зоні критичного застосунку і відсутності сторонніх осіб біля комп'ютера. На основі аналізу сучасних технологій зчитування і первинної обробки інформації з веб-камер онлайн були відібрані технології, реалізовані в бібліотеці MediaPipe, для подальшого використання у вирішенні поставленого завдання. Розроблені механізми моніторингу тих чи інших факторів, наявність яких необхідно постійно перевіряти для контролю наявності уваги працівника на активній зоні критичного застосунку і відсутності сторонніх осіб біля комп'ютера. Програмно реалізовано об'єктно-орієнтованою мовою програмування Python, використовуючи бібліотеку MediaPipe, розроблені механізми та за результатами проведених експериментів доведено доцільність їх використання для вирішення поставленого завдання. **Висновки.** Наукова новизна отриманих результатів полягає в наступному: ми сформували перелік факторів, наявність яких необхідно постійно перевіряти для контролю наявності уваги співробітника на активній зоні критичного застосунку і відсутності сторонніх осіб біля комп'ютера та вдосконалили технології розпізнавання обличчя, що дозволяє отримати рішення задачі контролю уваги користувачів критичних застосунків в неідеальних умовах.

Ключові слова: критичний застосунок; геометрія обличчя; мапа орієнтирів; уважність; MediaPipe; нейронні мережі.

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