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Discerning the Human's Emotional Instability Using Pupillography

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Abstract

Modern emotions discerning biometric systems that are currently developed are passive and aim at identification of psychological state of a human from his/her mimics. Existing systems successfully recognize basic emotions by facial expressions and determine drug and alcohol intoxication by "glassy eyes". However, the task of establishing a link between the emotions experienced and possible subsequent actions is yet unsolved. This happens as the size of the pupil strongly depends on the illumination and the uncertainty of the initial state of the pupil. The aim of the work is to describe a method of active recognition of emotions, based on the evaluation of pupil size against time during active testing. Test objects assume a form of audio or video information; the pupillography is recorded as the subject reacts. The idea behind selection of test objects dictates that the reaction to them should significantly vary between ordinary and potentially dangerous peoples. The article presents the first results. Video and audio files developed for the investigation of the pupil reaction to the information received by brain allows to evaluate the stability of the emotional state of a person. The results will allow to create a system of active recognition of individuals, who pose a potential danger to the society.

Introduction

Today the one who masters the rapidly developing technologies faster, wins. This fully applies to the technologies of prediction. Pupillography can be classified as such.

It was once believed that the purpose of the pupils is the adjustment of the luminous flux falling on the eye surface. Modern studies have revealed the complexity of the visual nervous system reaction. The facts confirm the relation of the pupil reaction to different areas of the brain. The wide application of pupillography in different countries confirms the high reliability of the results it yields.

The interest in detecting human emotional states from various biometric data (electrodermal activity (Ayata *et al.* 2017; Prasolenko *et al.* 2017), pupillography (Sirois & Brisson 2014), and profiling (Rossi *et al.* 2017) is becoming more common every year (Panksepp 2004; Maddess & James 2006; Mokrik & Zaplatinskiy 2014; Vozzhenikova & Kuznetsov 2014). The tasks of recognizing emotional valence is not fully resolved despite much effort already spent. Pupillography is used in many areas; dangerous individuals under the influence of drugs and alcohol can be identified (Monticelli *et al.* 2015). However, the carriers of evil intent remain unrecognized. The problem is not in finding pupils on the image, but in the identification of emotions. The standard method of determining emotions from mimic changes is good, but if a person has high level of self-control, it is difficult to recognize evil intentions. Therefore, the need to improve the existing method for recognition of hidden menace remains relevant.

A literature overview on the recognition and identification of potentially dangerous people indicates a wide application of biometric methods. Identification by voice, face, hand, eye in the bulk exceeds the classical fingerprint identification systems, which, in turn, use different principles for obtaining a fingerprint image, namely: total internal light reflection effect optical scanners, CMOS capacitive sensors, fiber optic chips and heat register chips. The number of companies engaged in biometrics has increased and approached 400. Accordingly, the number of areas in which biometric systems find real application, has increased. The most popular of them are mobile communications, passport systems and credit cards (non-cash payments). Large companies engaged in different areas of biometrics cooperate and unite, for example, Vision & Identix (total number of shares amount to $600 million). The effectiveness of biometric protection is extremely high, as it allows to accurately identify the person; the chance of unauthorized access with such protection is extremely small (no more than 0.1%) (Akhmetvaleev & Katasev 2016).

Due to cultural and ethnic differences in the emotional sphere, it is not always possible to use standard emotional stimuli in experiments (International Affective Picture System, LAPS, University of Florida, Gainesville, FL). On the basis of critical considerations, the authors of a number of reviews (Bekmurzin *et al.* 2014) come to the conclusion that the color sensitivity of the eye does not allow to evaluate if a person experience liking or disliking from the size of the pupil with certainty. However, the great progress of optoelectronics and digital technologies stimulates continuous research in this direction using new approaches and methods. The goal is to develop a method for relating the pupil size changes to the emotional state of a person. The article describes the pilot version of the method for determining a person's emotional response.

Literature Review

Pupillography is quite common thanks to the relative ease of implementation. For example, the pupillograph records the change in the size of the pupil along with speech (Stern *et al.* 2001). If a person lies, he/she experiences stress, the size of the pupils changes, which is registered by the pupillograph. The use of pupillography in studying the autonomic nervous system allows us to investigate various neurological abnormalities (Bekmurzin *et al.* 2014), diagnose Alzheimer's disease, neuropsychiatric disorders, sleep disorders, migraines, Parkinson's disease. By the change in the normal pupillary reaction, it is possible to judge the presence of diabetes in the early stages of the disease, amyloid and rheumatic disorders, and Chagas disease, one of the most common parasitic diseases in Latin America. Pupilograms are actively applied for diagnostics in ophthalmology (Ershova *et al.* 2014), neuropathology (Zaplatinskiy & Kovivchak 2013), narcology (Fomenko *et al.* 2018), and in general medical practice.

In 2008, Wilson and a group of researchers noted that the dynamics of pupil diameter can be used as an indirect measure of brain function. Fomenko *et al.*. (2018) clearly established the effect of mental load on the size of pupils and presented mathematical model of such reactions (Gukasov *et al.* 2012). Hypoxia will also change the reaction of the pupils to light. Maddess and James (2006) investigated the functional relationship of the reaction of pupils by simultaneous and sequential exposure of the eye to visual stimuli. This allowed to build a map of the visual functionality of the eye's visual field, which will help to conduct all the future eye reaction experiments with greater accuracy.

The relationship between the intensity of the stimulus and the scale of the pupillary response was described by nonlinear functions (Sanakoev *et al.* 2017). The reaction of pupils to pain was studied by Ukrainian scientists Mokrik and Zaplatinskiy (2014). Application of profiling in the area of aviation (transport) security was developed by Vozzhenikova and Kuznetsov (2014). Specialists of the Center for Measuring Technologies and Automation, Faculty of Physics, Moscow State University, developed "VizioSKAN" - a mobile system that tracks the direction of sight of the driver of a moving vehicle, which improves safety on the roads (Varlataya *et al.* 2016). Akhmetvaleev and Katasev (2016) presented the concept of contactless identification of people under the influence of alcohol and drugs, posing a threat to public safety.

The generally accepted biometric methods currently used in real life include methods of recognizing and identifying an individual by face and by the iris of the eye. The advantage of these methods is no need for contact. The first of them allows to recognize basic mimic emotions, but specially trained people escape such systems. Biometrics on the iris allows to identify a person, but says nothing about the emotional state. In the Belarusian State University of Informatics and Radioelectronics, Zhabinskiy (2014) studied the role of texture (pixel intensity) in the task of recognizing emotions in a human face.

Tomsk Polytechnical University researchers, under the leadership of Druki (2011), have developed an algorithm for detecting a face and algorithms for recognizing a person's emotional state against a complex background.

The mentioned systems for emotion recognition by facial expressions need algorithms that can receive different image segments with different levels of image noise in a short time. Algorithms have been successfully implemented both abroad (Leon-Sarmiento *et al.* 2008; Wilhelm & Wilhelm 2003; Maslova 2017; Merritt *et al.* 2004; Dacey *et al.* 2005) and in Russia. Scientists from St. Petersburg designed a program for recognizing and training emotions in C #. All the supporting algorithms are implemented: Viola-Jones object detection, image binarization algorithm and Sobel filter; the neural network was trained successfully; It was possible to achieve an acceptable level of accuracy for the existing training set.

The signs of vitality (signs of life) analysis allow detecting the falsification of information presented by an individual in face recognition systems. Kostylev and Gorevoy (2013), from Moscow State Technical University, use the analysis of the spectral characteristics of the reflection of human skin (non-contact method) as an indication of vitality. Local minima and maxima are stipulated by the presence of hemoglobin in the inner layer of the skin. The effect of facial expressions, speech, blinking or emotions on the result of recognition, the properties of the skin or eye tissues, blood pulsation in vessels and capillaries, eye movements, accommodation, and the natural response to a particular effect can also be utilized as indicators of vitality. The normal constant oscillations of pupil sizes (Varlataya *et al.* 2016) is used to check the activity of the eye in the iris recognition systems. The voice is also used for identification of a person and his/her emotional state. This method is suitable for remote use and requires cheap technological equipment, but produces a high error rate.

In the United States, Israel, and Germany, biometric recognition systems are being tested at stadiums, in the subway, airports, etc. According to Vozzhenikova and Kuznetsov (2014), Akhmetvaleev and Katasev (2016), Volkov & Semenova (2012), emotions can be determined. The development of the existing information technologies and emergence of new ones led to the appearance of human-computer interaction (HCI) and the introduction of the concept of "affective computing". The machine is taught to identify and respond accordingly to the user's feelings and emotions, determined by facial expressions, posture, gestures, speech characteristics, and even body temperature (Rossi *et al.* 2017; Danilova & Krylova 2005; Gnezdickiy 2003; Kolker 2004; Meshchaninov & Ldovskaya 2015).

Methods

The proposed method comes down to assessing the emotional response of a person using the pupillogram recorded during comprehension of information, in response to an emotionally colored test object that is the carrier of this information. A specific feature of the developed method is that test objects have a differentiated (adjusted to the subject's individual perception) informational impact on a person and that the method

Tab. 1. Factors, affecting the size of the pupil

	Influence method, €					
	Informational, external, Ψ	Informational, internal, Ψ0	Chemical, Ђ0	Physical, Ω0	Biological, £0	
					Random	Constant
Source (examples)	Test objects: video, announcements, news, people, etc.	Thoughts, mood	Smell in the room Medicine, alcohol, drugs Random smells, Food	Light, sound, illumination, air temperature, humidity	Pain attacks	sex, age, nationality, illness
Length of affect	from τ to t	t	from τ to t	from τ to t	τ = t, Periodically	t
Degree of the affect on the size of the pupil	Depends of the itensity of iritaion factor Ψ	Depends on the intensity of the irritation agent Ψ 0	minimum Ђ strong weak	Depends on the intensiyt of the irritation agent Ω0	Depends on the intensiyt of the irritation agent £0	const
Possibility to correct the parameters of the method externally	In the majority of cases	In the majority of cases	yes no yes	Yes in the majority of cases	No / minimum	No
Conditions of the registration of emotional reaction of the pupil on the test object	Ψ > Σ €	Ψ > Ψ0	Usually Ψ >> Ђ0 Glassy pupil Ψ > Ђ0	Ψ>Ω0	Ψ>£0	
Critical limitations	Σ € <iΨ< $\Psi_{activation}$					

itself serves as an addition to the existing recognition methods.

Thus, in the developed method, we will use stimuli (test objects) that have a specific thematic focus. They will, therefore, have an emotional impact in proportion to the degree of an individual's internal commitment to this subject. At the first stage of the experiments, different images were used as emotionally colored test objects. The information on test objects, was determined by topical problems of society, for example, nationalism. The level of intensity of emotions aroused by the information was assessed statistically. The average value was considered a normal reaction, since the most people were hypothesized to be mentally balanced and tolerant.

In order to use this method, one must be sure that the reaction registered is the response to the test object. From the point of view of the influence method (denoted as €) leading to a change in the size of the pupils, the existing factors can be conventionally divided into informational (direct effect of information on the brain) and non-informational (indirect effect on the brain). The list of factors affecting the pupil and their characteristics are presented in Table 1. Non-informational factors include exposure to chemicals (including common medicines and food), physical (light, pain, etc.), biological (temperament, age, gender, illness, etc.).

We shall consider the minimum time required for the transmission of information, sound exposure, the onset of the drug effect, etc. as short time of exposure τ. The total time during which an individual is under observation is denoted by t.

Hypothesis: each person has topics that cause extreme emotional responses. Information related to them causes involuntary attention if it appears in the field of perception of an individual. If we assume that a test object contains such information, the reaction of the pupils to such a test object is proportional to the intensity of the emotions experienced (Ψ). $\Psi < \Psi_{activation}$ corresponds to afferent synthesis that does not lead to active actions. The information does not change the emotional state of individual to who it is of no relevance, and the size of the pupils is normal. The fluctuations of the pupil area stay within the normal limits (not more than the average ΔS) and are determined by the factors $€ = £0 + \Omega 0 + Ђ0 + \Psi 0$. The evoked potentials of the brain are known to correlate with pupillograms (Gnezdickiy 2003; Kolker 2004). This way we obtain values that can be picked as critical.

Thus, to register the response of the pupil to the test object, it is necessary to stabilize Ω_0, to secure $\Psi > \Psi_0$, $\Psi > Ђ_0$, $\Psi > £_0$. The random and constant components contribute to the factor $£_0$. The constant component of the biological factor is accounted for naturally by the recognition system, since it is controlled by the relative size of the pupils; so do the physical, chemical, and informational components. The random component of the biological factor $£_0$ is highly unlikely to correlate with the response to the test object thanks to a large number of test objects of various types. For the reaction of pupils to test objects to be reliable, the amplitude of the evoked emotions must exceed the maximum value of the error significantly. Each of the factors mentioned in table 1 contributes to the error Δ, as well as by the random statistical and methodological errors in the contouring of the pupils do.

The following points are to be taken into account by selecting test objects:

- The target category of individuals
- if the eye surface illumination during recording of the pupillograms varies, it is necessary to introduce a correction factor;
- the level of emotions should not urge a person towards onset of actions. The intensity of the stimulus should lie in the interval $\Sigma € < \Psi < \Psi_{activation}$.

The latter is the most difficult to secure.

CCTV operates to ensure security in crowded places. Upgrade and calibration of such systems will allow to conduct a comprehensive analysis of the psychophysical state of people. The function $ȹ = \phi_0 + ȸ + \omega + ɩ$ describes the psychophysical state of a person at the initial moment of observation. Thus, one requires neutral test objects, bearing no information or non-essential information for people of a certain type. Such test objects allow to "tune" the system to a specific individual, to account for spontaneous oscillations of the pupil and for the random noise. To render the pupil area independent of the direction of the subject's stare (close or far, up or down) and squinting, the test object should be located at a sufficient distance determined by a preliminary general calibration of the system.

A person distributes attention to objects or circumstance that are significant at the current time. Attention focuses on the object more often than the higher its subjective significance. Significance is due to the motivational force and information richness of the object. Therefore, the determining factors for success will be the novelty of the informational stimulus and the correspondence of the stimulus to the internal state of a person, his needs, that is, the condition $\Sigma € < \Psi$ is fulfilled.

Attention is characterized by dilated pupils, an increase in skin conduction, a decrease in heart rate, a change in respiration, widening of the head vessels, and shrinking of the hands vessels. A loud sound, a bright flash of light, a strong odor attracts involuntary attention (Akhmetvaleev & Katasev 2016).

The so-called afferent synthesis, related to higher nervous activity, stipulates the reaction of an individual to external stimuli (Danilova & Krylova 2005). $\Psi < \Psi_{activation}$ corresponds to afferent synthesis that does not lead to active actions. The behavior depends on the processes developing during the stage of afferent synthesis. In turn, several factors determine the content of afferent synthesis: motivational arousal, memory, situational afferentation, and triggering afferentation. The fragments of past experience relevant for future behavior are extracted from memory at the afferent synthesis stage. Next is the efferent synthesis with the integration of somatic and autonomic excitations, when the action has already been formed, but is not yet implemented. The nervous system compares the expected results with the incoming afferent information on the possibilities real world provides. The results of the comparison determine whether the individual will proceed to action (Volkov & Semenova, 2012).

Results

A helmet providing a rigid coordinate connection between the video camera and the head (Fig. 1.a) is developed to study the pupil response. The helmet is a copper tube frame. The frame is covered with a layer of foam rubber. An adjusting screw In the back of the frame allows to loosen or tighten the helmet on the head. A person wearing a helmet is seated at a distance where the eye illumination variation is insignificant. The distance was picked basing on measurements of the illumination created by elementary test objects at distances of 0.75–4 m from the luxmeter photometric head (Fig. 1.b).

The possible contribution of test objects to the pupil illumination was evaluated using the pupillograms recording setup, in which a photometric head of a luxmeter took place of a subject. Elementary test objects were a set of monochrome slides of different colors. The experiment was conducted at nighttime behind the curtains, without artificial illumination, from an LCD monitor. The screen brightness remained unchanged in all the experiments and the luxmeter surface was only illuminated by the test objects glow. The distance between the test objects and the eye was sequentially changed from 0.75 m to 4 m, with a step of 0.25 m. Thus, the distance at which the stimuli did not contribute to the change in the size of the pupils was determined.

Starting from slide 19, emotionally colored pictures appeared in the sequence. The emotional strength of them on a scale from 1 to 10 does not exceed 4, where 10 is the strongest emotion possible. The video was captured using a T7 Astro Camera Astronomical Astronomy Telescope Digital Lens for Guiding Astrophotographer video camera, 30 fps, 1X-100X optical zoom lens.

Pupilograms were obtained from groups of two age categories (16–25 years old and 45–50 years old), 10 and 5 people respectively, both males and females, with no history of eye illness. Illumination was further monitored by subject's skin tone (in the scale of gray, normalized by the mean value). By second testing the reaction of the pupil was indistinguishable.

During testing, participants heard an audio message stating that they were expelled from the university (with the name of the participant). The ratio of the gray level, $k=I/I_{max}$, is the smaller, the darker the picture ($I_{min}=0$, $I_{max}=255$).

A typical result of the pupil response to test objects in experiments with different age groups is demonstrated on Figure 2.

After calibrating the pupil observation system and the first series of experiments, an experiment was conducted on a group of students to record a gradient of emotions "interest-fright". Before the standard test procedure, the distance between the monitor with test objects and the participant was reduced. Thus, the illumination had a significant impact on pupil size. The results are presented in Figure 3.

The graph demonstrates that the intensive growth of pupil size (solid line) continues along with the increase in the relative level of gray (dashed line) k and its further stabilization. By testing with low significance visual test objects the maximum dispersion of the pupil area is 0.2 Scp. When using high significance test objects the pupil area increased 1.5 times in 0.5 s. This shows that the pupil size grew independently

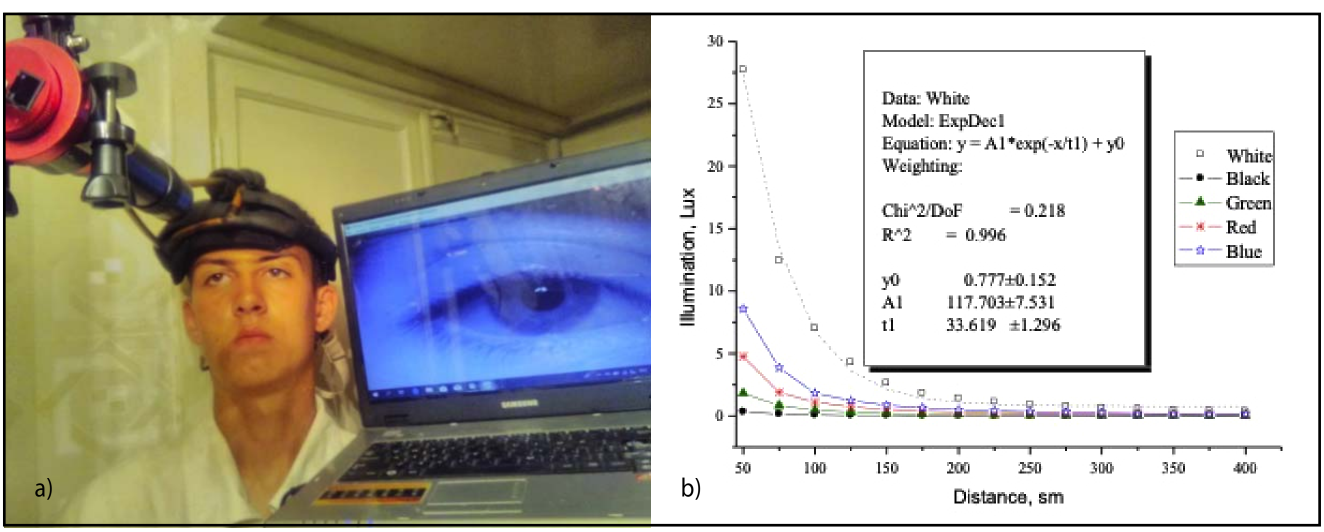

Fig. 1. a) Pupillogram recording setup; b) Illumination created by test objects on a photosensitive matrix

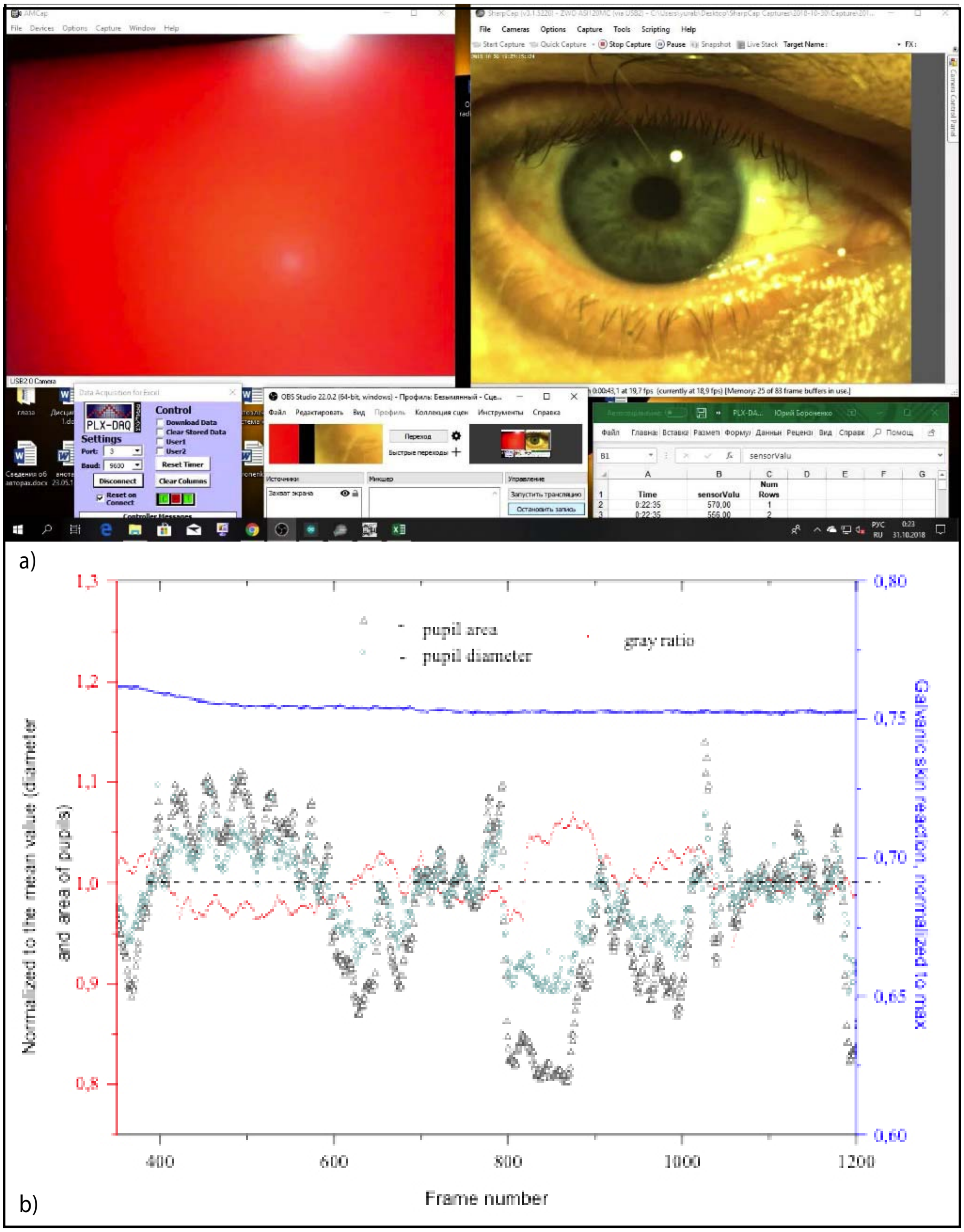

Fig. 2. a) Software system synchronization; b) Pupil response, electrodermal response to test objects

of the light, it was caused by emotions gradient. The dilation or contraction of the pupil depends on the current balance between sympathetic and parasympathetic nervous systems. In this case, disturbance of the sympathetic section caused pupil dilation (with fear), which indicated readiness for action. The experiment shows that the pupil's reaction to the important information will exceed the level of interference from lighting or another source. Thus, an important step in the application of this method is the establishment of an emotional threshold, which is characterized by the "speed" and "frequency" of engaging an individual in one or another emotional state and provokes action.

The statistics for assessing the intensity of test objects was accumulated both online and in the presence of teachers. The students' emotional reaction was monitored along with response. In some cases, the participants reacted with vigorous commentaries and aggression. Personal beliefs stipulated the different emotional reactions. In this case, simple pictures carried information that is significant for the individual. Emotionality was individually activated.

In experiments with audio stimuli, the pupillary response was observed. Important information contributed to the increase of the pupil's size. The moment of reporting information was not perfect, as the gray

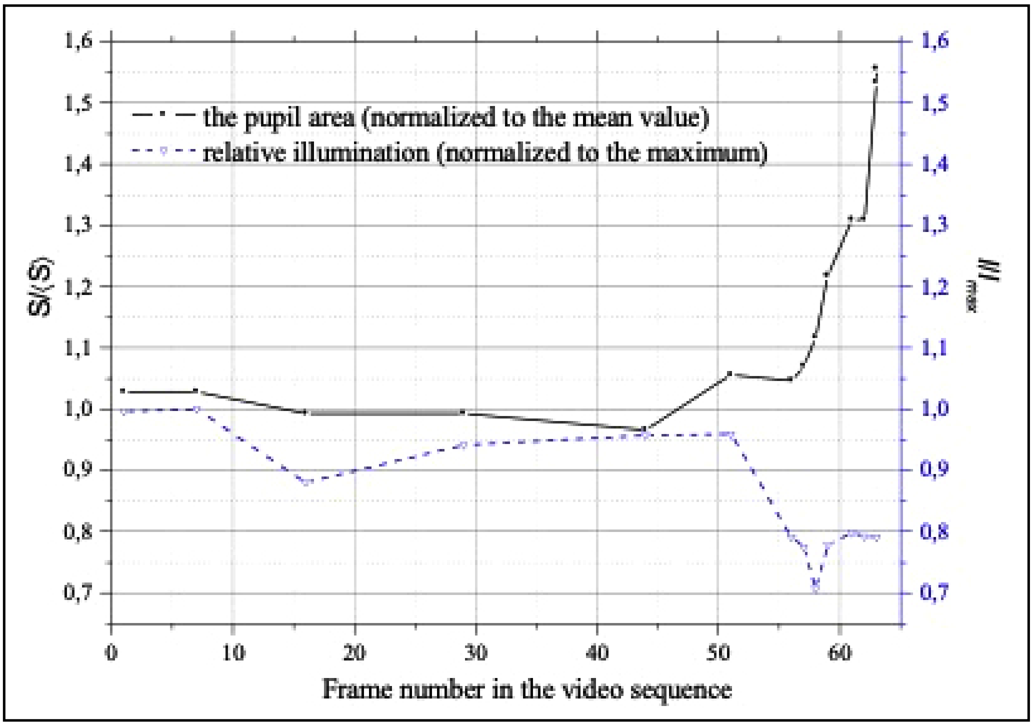

Fig. 3. The reaction of the pupil to the test object containing information relevant to the subject

coefficient $k=I/I_{max}$ decreased, i.e. the color of the test object at the start also contributed to the growth of the pupil. However, after the 60^{th} second, the color of the test object did not change and the growth of the pupil is explained only by the emotional state of the person. Observing the emotional reaction of the subject, the operator turned off the recording of the pupillogram. Visually, the growth of the pupil continued for some time.

Discussion

To improve the results of the experiment the video stimuli must contain a transition from a dark scene to a light one. Two competing processes will arise: the illumination will help to shrink the pupil, and the emotions will "force" the pupil to widen. Then, depending on the information degree of significance, the size of the pupil either does not exceed or exceeds a certain level after which a person can be considered potentially dangerous.

Affectiva, founded by Rosalind Picard (1997) and her MIT graduate student Rana el Kaliouby, opened access to their SDK on Unity for experimenting, testing, and implementing various micro-projects. Currently, the company has the world's largest database of faces analyzed. Almost all foreign companies use biometrics not only in cell phones. For example, Sentio Solutions is developing a Feel bracelet that tracks, recognizes, and collects data on human emotions during the day. At the same time, the mobile application offers tips that aim to form a positive emotional habits of the user. Sensors built into the bracelet monitor several physiological signals, such as pulse, electrodermal reactions, skin temperature, and the algorithms of the system translate biological signals into the "language" of emotions.

Security surveillance systems at a particular airport (Meshchaninov & Ldovskaya 2015) use of vibroimages. Technically, the vibroimage is the accumulated interframe difference in each element of the video image. This computer image processing is carried out in real time and allows you to use the resulting vibraimage as a database for determining the individual's psycho-emotional parameters, for example, the level of aggression, stress, anxiety, and potential danger. New biometric technologies developed by Elsis: volume pulse (3D-pulse) and vibroImage make it possible to get more than 10 million readings per second on the psycho-physiological state of a person and can be used to build third-generation biometric systems (Picard 1997; Panksepp 2004; Maddess & James 2006; Mokrik & Zaplatinskiy 2014). They are capable of simultaneously carrying out the identification and testing of the user's thoughts within 10 seconds (Mokrik & Zaplatinskiy 2014; Akhmetvaleev & Katasev 2016; Volkov & Semenova, 2012; Vozzhenikova & Kuznetsov 2014).

Pupilograms have been used in the diagnosis of emotional states for at least 30 years (Sirois & Brisson 2014). The eye tracker study (Kreuzmair *et al.* 2017) demonstrated that fake personalized medical diagnoses cause a visible reaction — a similar model was used in this study. The size of the pupil as a correlate of psychological stress is indicated, in particular, by the study (Stolarska-Weryńska *et al.* 2016). At the same time, studies demonstrate that the pupil diameter is not a discrete, but a continual parameter — the degree of stress corresponds to different pupil diameters (Pedrotti *et al.* 2014), and there are results indicating that it is possible to automatically classify the degree of stress by this parameter. These experiments show the potential for development in the field of automatic detection of malicious intent by the pupil diameter.

Thus, identification and recognition systems based on the assessment of the emotional state and facial expressions are the most promising for use in security systems (Leon-Sarmiento *et al.* 2008; Wilhelm & Wilhelm 2003; Maslova 2017; Merritt *et al.* 2004). When developing systems for recognizing potentially dangerous individuals, the overwhelming majority of researchers focus on mimic biometric data (Dacey *et al.* 2005; Ayata *et al.* 2017; Prasolenko *et al.* 2017; Sirois & Brisson 2014; Rossi *et al.* 2017). The biometrics effectiveness for identification is extremely high, as it allows you to accurately recognize a person and the probability of error is not more than 0.1%. However, the video surveillance system should not only carry out automatic scanning of faces and identify them in the database, as well as analyze basic unhidden emotions. The main task is to identify those who are going to commit a crime by certain markers.

Conclusion

Research demonstrated that under the influence of low significance test objects the emotional state remains almost unchanged, a slight change in the amplitude characteristics of the pupillograms (maximum dispersion is 0.2Scp) is observed. Consequently, using test object with important information allows to achieve a pupillary reaction that exceeds the reaction caused by other factors, which makes it possible to reliably recognize instability of the emotional state of a person.

Thus, the test objects (video and audio files) used to study the reaction of the pupil to the information incoming to the brain are important for individuals of a certain category, becoming specifically "activating".

Subsequent research needs to address establishing a critical level of $\Psi_{\text{activation}}$ of permissible emotions and accumulation of statistics.

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