Determination of the fear coefficient by pupillograms

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Abstract. Currently, various mathematical models of pupillograms are used to process the results of pupillometric studies. There are also mathematical models of emotions. At the moment, research doesn’t combine modeling of pupillograms and modeling of emotions. In our work, an attempt was made to determine the fear coefficient by pupillograms. For research, an optoelectronic installation has been developed. As an example, we give an example of the analysis of pupillograms of people of an older age category. A mathematical model of the pupillogram plot is obtained, obtained in response to fear emotion.

1. Introduction

The issue of the course of emotions has been studied to some extent. It is known that the size of the pupils depends on the size of the emotions experienced. However, the existing mathematical models of pupillograms mainly describe the reaction of the pupil to light: linear, nonlinear, Bezier curves. Therefore, the search for a mathematical model that describes the pupillary reaction due to emotion is relevant. At the moment, studies do not combine modeling of pupillograms and modeling of emotions. In our work, an attempt is made to determine the fear coefficient by pupillograms.

2. Overview

Currently, various mathematical models are used to process the results of pupillometric studies: piecewise-linear models of pupillograms, approximation models, Bezier curves, nonlinear models [1], artificial neural networks [2].

Existing models of emotions are quite diverse: the OCC model [3], the Plutchik model [3], the multimodal emotion recognition system [4], the model for modeling mood dynamics based on psychological theories about unipolar clinical depression [5], the model based on algebraic representation emotions [6], a mathematical model of fear, taking into account generalized information about a possible threat stored in memory, and incoming information about a real (or expected) threat [7], a mathematical model of the subject’s emotional state - KL-model [8], a mathematical model of emotional process in the form of the Cauchy problem for a system of ordinary differential equations [9].

The purpose of our study: based on experimental data, determine the fear coefficient by pupillograms.

Tasks:
1. Selection of test objects that cause an emotional response;
2. Assembly and calibration of the experimental setup, allowing to register changes in the size of the pupil;
3. Selection of a mathematical model of the pupillogram plot.
4. Comparison of the theoretical coefficient of fear and plot pupillograms based on experimental data.
3. Experimental part

The study is based on the dependence of the size of the pupils on the emotions experienced. Information that is significant for a person causes involuntary attention if an individual appears in the field of perception. If we assume that the test object may contain such information, then the reaction of the pupils to such a test object is proportional to the intensity of the emotions experienced in this case. Before the experiment, a survey was conducted to determine the topic of interest to the subjects. By agreement with the participants, test objects containing the emotion “fear” were selected.

The optoelectronic installation is shown in Figure 1. A helmet has been developed for research, with the help of which a rigid coordinate connection is created with a video camera. Camcorders 1 and 2 are attached to the bracket with standard mounting bolts. Bolts allow you to direct the lens at the pupil of the eye by adjusting the angle of inclination. It is also possible to adjust the distance between the lens and the eye. The first camcorder registers an image of the monitor on which video files were displayed. A second video camera records the size of the pupil. The internal time of the cameras is synchronized up to hundredths of a second. This allows you to determine the cause of the resizing of the pupils. A person wearing a helmet is located at a distance at which the change in the illumination of the surface of the eye due to the glow of the monitor becomes insignificant.

Figure 1. Optoelectronic pupil size registration system: 1 - a camera that registers the image of the monitor on which video files were displayed; 2 - a camera recording the size of the pupil; 3 - helmet, creating a rigid coordinate connection with the head.

As an example, we give an example of the analysis of pupillograms of people of the older age category (50-75 years), in which representatives of different sexes were present. In total, more than 100 people took part in the experiment, including full-time and part-time students. All participants in the experiment were volunteers, and were warned of a possible emotional experience. Basically, all participants have hyperopia, one woman has myopia corrected by glasses. To evoke emotion, we used a video about accidents that were freely available on the Internet.

4. Discussion and main results

The average value of the level of intensity of emotions was considered a normal reaction, since the hypothesis was that most people are mentally balanced and tolerant. Since the size of the pupils depends on the emotions being tested, their intensity can be estimated from the pupillogram. The pupillogram-curve of the intensity of emotional experience is presented in Figure 2.
Figure 2. Pupillogram - curve of the intensity of emotional experience

The whole process lasts for time t, where the area of 0-6.84 s is the total time during which information about the real or expected threat is collected, the area of 6.84-9.5 s is the time interval between the moment of reaching the peak of fear coefficient and moment of appearance of the effect of removing fear, and the last area is the decay time of the emotion, during which the normal state returns [8].

Assume that the change in pupil size is due to information entering the brain from test objects. Then the intensity of the emotions experienced depends on the coefficient of fear [9]:

$$S(t) = f(t) \times S_0.$$  \hspace{1cm} (1)

After its occurrence, the intensity of emotional experience increases (0-6.84s), reaching its maximum value at $\tau = \tau_{\text{max}}$. The latter value is defined as [9]:

$$\tau_{\text{max}} = \tau_0 + \left(\frac{1}{k_2}\right) \times \ln S_i$$ \hspace{1cm} (2)

where
- $\tau_{\text{max}}$ - the moment of the highest emotional experience;
- $k_2$ - coefficient of updating pragmatic information;
- $\tau_0$ - the beginning of emotional experience;
- $S_i$ - the Simonov number.

Subsequently, the intensity of emotional experience decreases exponentially, asymptotically approaching the initial state.

There is a threshold value of perception of emotion individual for each person.

When the intensity of the emotion reaches its threshold value, a person ceases to feel it [9].

From theory [8], at any time t, the fear coefficient is defined as
\[ f(t) = \frac{A}{Q - \frac{I_0}{k}(1 - e^{-kt})} = \frac{A}{Q - \frac{I_0}{k}(1 - \frac{1}{e^kt})} = \frac{A}{Q - \frac{I_0}{k}(\frac{e^kt - 1}{e^kt})} \] 

(3)

where

Q - generalized information about a possible threat stored in the individual's memory;
\( I_0 \) - cumulative incoming information about the expected threat;
A is a certain real constant characterizing the process of fear. In this case, for A = 1, it is appropriate to take the normal size of the pupils.

From the experiment, a function that describes the process of increasing emotions \( k = -k \):

\[ F(t) = a + \frac{b}{k}(e^{kt} - 1) = a - \frac{b}{k} (\frac{1}{e^{kt}} - 1) = a - \frac{b}{k} (1 - e^{kt}) \] 

(4)

\[ F(t) = a - \frac{b}{k} (\frac{e^{kt} - 1}{e^{kt}}) \] 

(5)

Suppose that the change in the size of the pupil is due to information entering the brain from test objects. Then the intensity of the emotions experienced depends on the coefficient of fear \([8]\):

\[ f(t) = \frac{1}{a - \frac{b}{k} (\frac{e^{kt} - 1}{e^{kt}})} = \frac{1}{F(t)} \] 

(6)

Using the attention track, you can determine on which element of the presented test object the reaction occurred. Also, using the track, you can determine that the reaction did not occur to the test object. Emotions should be adequate, that is, average. Any deviation from the norm requires close attention and study. With this, the resulting fear coefficient can help. Proper selection of test objects will expand the capabilities of eye-tracking, as well as improve existing security systems that use artificial intelligence and emotion recognition.

5. Conclusions

A mathematical model of the pupillogram plot is obtained, obtained in response to fear emotion. By the method of equivalent transformations over analytical expressions, the theoretical and experimental functions were converted to a form convenient for comparison. A comparison of the theoretical fear coefficient and the plot of pupillograms constructed on the basis of experimental data showed their syntactic similarity. This allowed us to find the coefficient of fear.

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